MAY 1952

Chemical Engineering Progress

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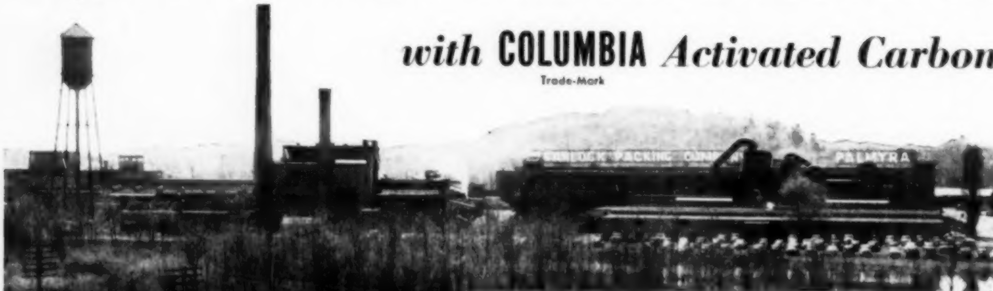
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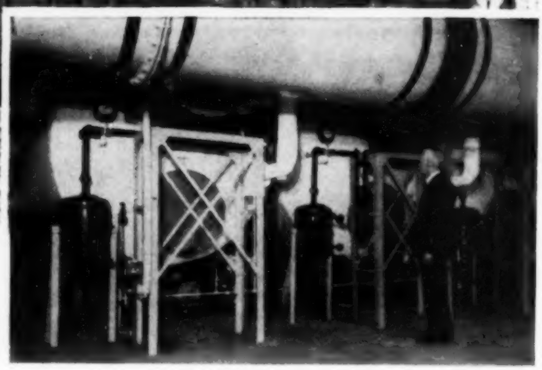

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OPINION AND COMMENT

ENGINEERING SECTION

NEWS

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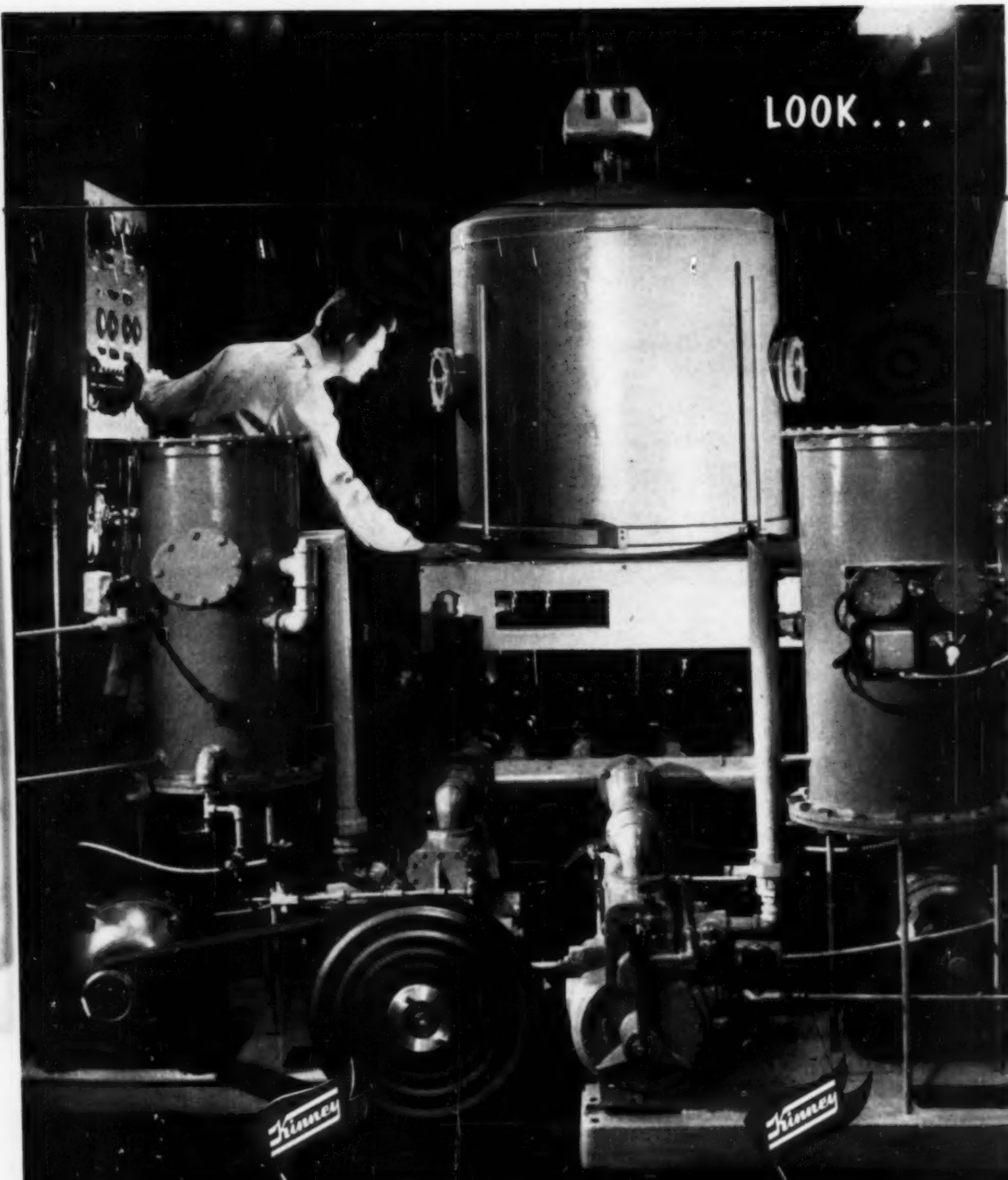
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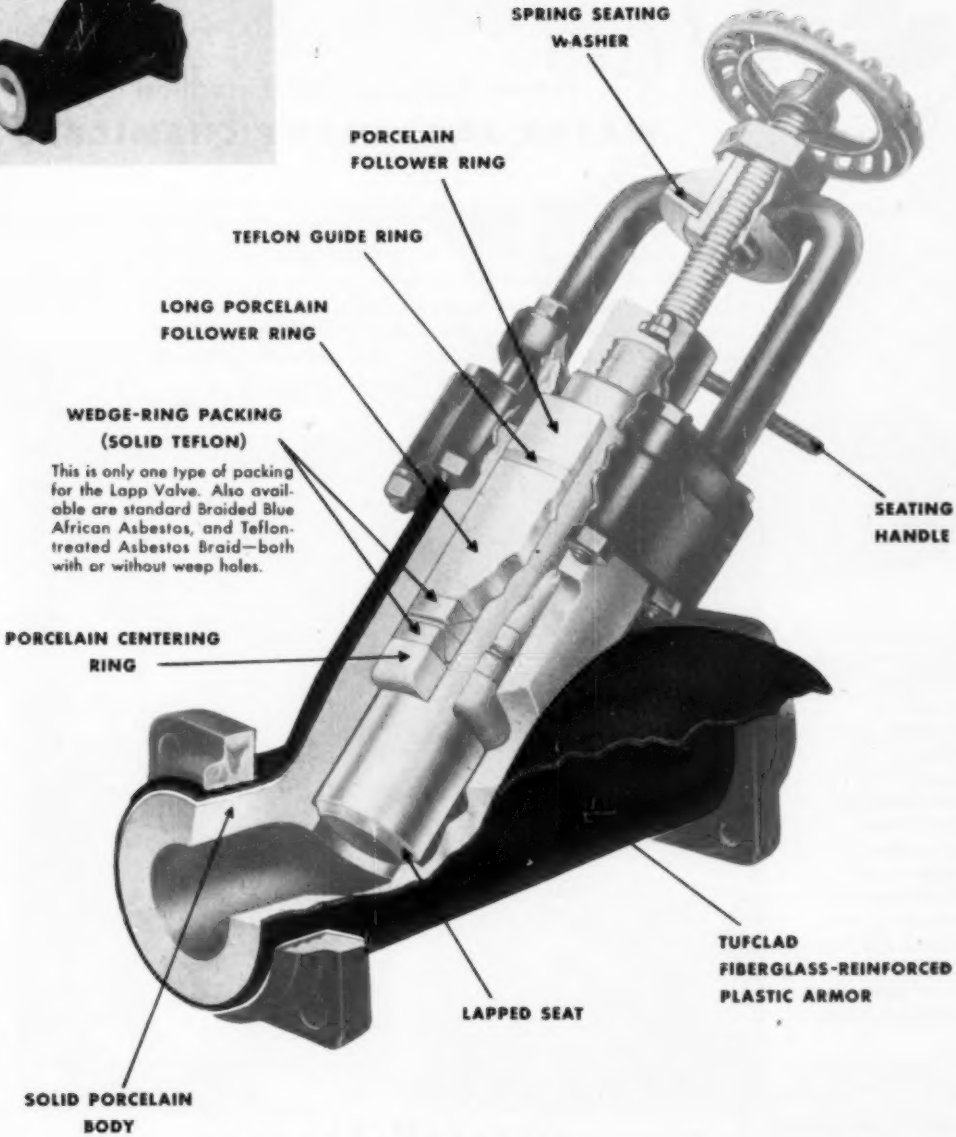

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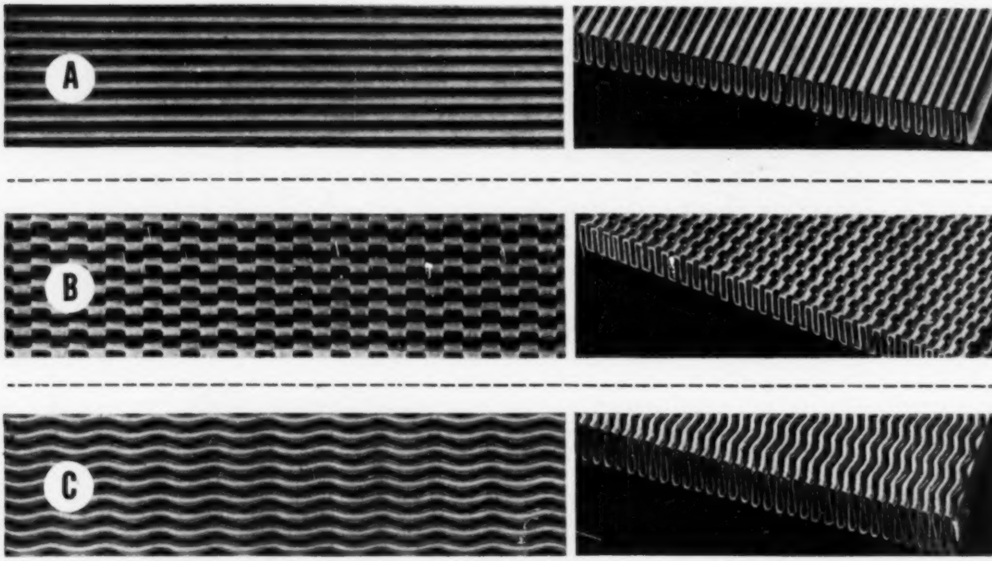

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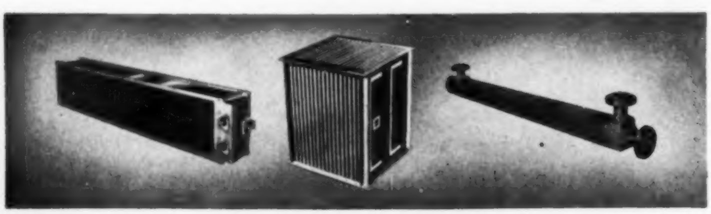
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OPINION AND COMMENT

PRODUCT DEVELOPMENT AS A CAREER FOR CHEMICAL ENGINEERS

THE profession of chemical engineering concerns itself primarily with the application of chemistry and engineering to the development of chemical processes, to the design and operation of chemical plants, and to the adaptation and improvement of equipment for carrying out chemical processes on an industrial scale. Indeed, qualifications for Active membership in the American Institute of Chemical Engineers require that the applicant "shall be proficient in the application of principles that pertain directly to processes and process equipment in which matter is treated to effect a change in state, energy content, or composition."

The chemical engineering curricula in our schools of engineering stress process development and plant design to such an extent that few engineering graduates realize that there are fields other than the process industries for which their training qualifies them.

This is written for the purpose of focusing attention on a field of professional activity that does not involve manufacture of chemicals, development of processes, or design of plants, yet one that affords a highly satisfying, remunerative career for the chemical engineer. This activity is variously referred to as "product development," "applications research," or "technological adaptation of products to industrial use."

The marketing of pure chemicals is a relatively simple matter. Since such products are of known composition, specifications can be written that define their characteristics with sufficient exactness so that the purchaser knows just what to expect in the way of performance, provided the products conform to the specifications. Furthermore, their use is generally established and there is little likelihood of encountering unexpected and undesirable results from lot to lot, or in going from the product of one supplier to that of another. In other words, there is no extensive technology involved in utilizing the established and well-defined products of the chemical industry.

The introduction of new products, particularly those of indefinite composition, may be a different matter. Such product development may involve the creation of whole new technologies before commercial utilization can be realized. Scientific personnel qualified to carry on this type of investigational work must have the broadest kind of training, because the problems encountered may range from the design and construction of equipment for handling, applying, or testing the products to physical or physicochemical studies of the phenomena presented. Much of the equipment for product development work is of a type familiar to the chemical engineer. Such items as autoclaves, stills, filters, dryers, presses, centrifuges, and the like, are used just as extensively in connection with product development work as they are in pilot plant operation and other strictly chemical engineering activities. Precision instruments and all sorts of testing equipment are likewise employed. In addition to broad engineering training and familiarity with equipment, it is requisite that the personnel engaged in product development have a high level of ingenuity. Usually there are no established procedures. The introduction of each product or class of products that merits applications research generally involves the development of a new technology which means that the procedures for utilization as well as for evaluation must be created as the work proceeds.

Chemists and physicists, although better trained in their particular specialties, nevertheless lack the broader training of the chemical engineer which, in addition to a thorough grounding in chemistry, extends from machine design to electrical engineering and from mathematics to thermodynamics. Consequently, it has been found that chemical engineers are uniquely qualified for success in the field of product development and are in great demand for this work.

ARTHUR K. DOOLITTLE

See General American for

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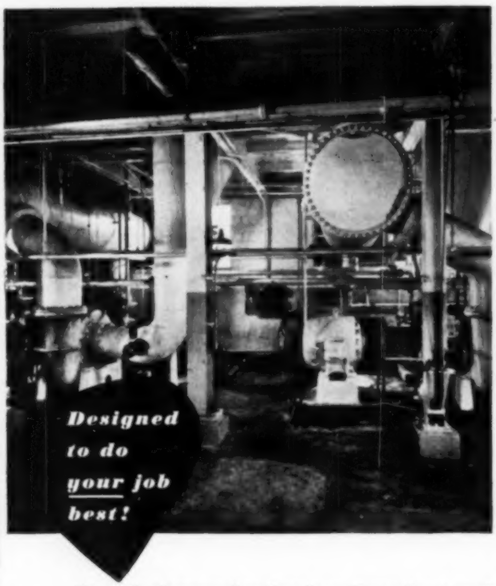
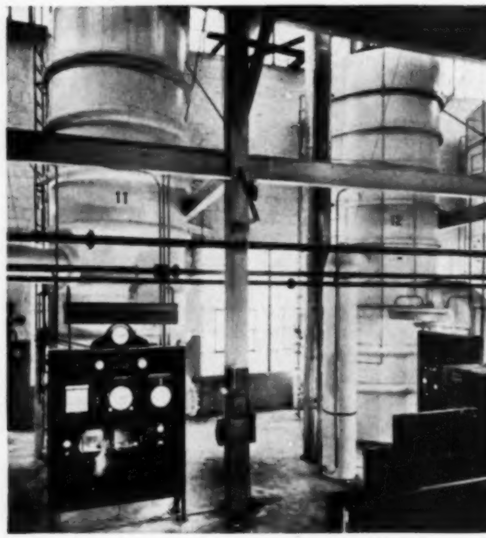
Reduce scale deposits . . . Boost production with Conkey forced circulation horizontal tube evaporators





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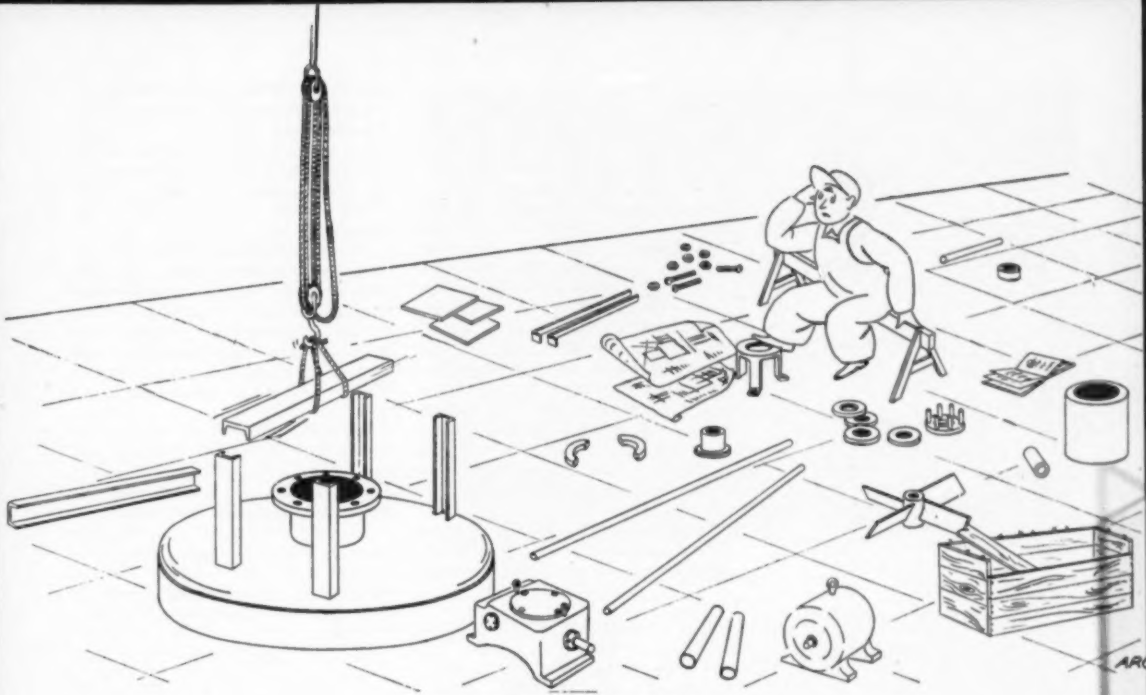


Fig. 1. Installing your mixer the hard way.

With this issue we conclude the series on Maintenance which was started in the February issue with an article on organizing a maintenance department and the adaptable personnel needed. . . . This was followed in March by some valuable suggestions on the importance of the original design and layout of plant and equipment. . . . Last month the "fix-it-before-it-breaks" philosophy was stressed . . . and this month our author discusses the installation of mixers after suitable planning and designing and offers rules of practice in their operation. . . .

MAINTENANCE OF FLUID MIXERS

R. D. BOUTROS

Mixing Equipment Co., Inc., Rochester, New York

Richard D. Boutros, affiliated with Mixing Equipment Co., Inc., Rochester, N. Y., as chief engineer since 1947, has given considerable thought and attention to the mechanical design and technical application of mixers. Prior to this assignment he served as factory superintendent and engineer. He has directed work on the critical speed characteristics of overhung shafts. He is currently supervising a project on the performance design of stuffing boxes. A graduate of the University of Virginia, he holds a degree in mechanical engineering.

EASY installation, trouble-free operation, and low cost maintenance must be founded in good design. In fact, these are tests of a good design. To get these at low cost is a prime engineering function. If equipment is selected or designed without taking into account the factors that affect installation, operation, and maintenance, and if the maintenance and operating departments are not given a chance to check design, the job is unfinished. The operating and maintenance men are then forced to make up for poor engineering and purchasing methods.

The maintenance department alone is not responsible for keeping a plant running. Even the best crew will have trouble keeping a poorly designed unit on stream. We ask the impossible if we also insist that the maintenance costs of such equipment be low.

Unfortunately, because the purchase price of equipment is a tangible, easy figure to get, it is stressed; installation and maintenance costs are rarely reported to engineering and purchasing.

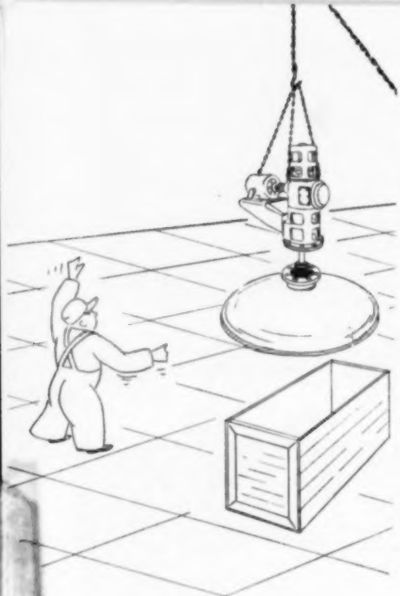


Fig. 2. The easy way.

The project cost is not solely the cost of getting the equipment. Money spent in time and materials to get the plant running is part of the cost also, and it is affected greatly by the equipment selected or designed. In some "low cost" units, the "savings" in purchase price are spent many times in keeping the unit running. When it isn't running down-time must be considered—an important and often overlooked item.

Down-time is expensive, and must be thought about in selecting, designing, or planning equipment. Down-time costs must be kept in mind when planning maintenance programs. If a plant operates continuously, there is no such thing as a "minor" unit. The failure of any part will stop the plant. Some units may cost more, may be more complex, may be harder to replace than others, but in a continuous system, "the chain is no stronger than its weakest link."

A shutdown means a loss in revenue of $1500 an hour to a twelve million dollar a year business that runs 95% of the year. A business, operating on an eight-hour day 240 days a year, doing the same volume, loses $6200 each shutdown-hour of work. Beyond shutdown losses might be product spoilage and premium costs for replacement parts.

It is impossible never to have a shutdown, but trouble can be avoided by checking designs with plant operators and maintenance men.

Some engineers think that standby equipment is the surest way to reduce down-time. This isn't always the best answer. If care is taken of a well engineered unit by sound preventive maintenance, a lower equipment cost per product-unit is possible than if the money was spent for standby machinery. Standby equipment often is a large capital investment. It earns practically nothing—it is idle too much. It is, in fact, an insurance premium for an uncertain degree of protection—unless it is given good care. Standby units must be ready all the time, and this cannot be done for nothing. If standby units are idle for long periods, oil seals, packing, and mechanical seals can deteriorate and lose their effectiveness. Bearings, gears, and other machine parts can corrode. Corrosion from condensation in idle machine housings is quite common. Unless standby equipment is checked regularly it may be unfit for service when you need it most.

While many factors of mixer design are beyond our scope here, some have a direct bearing on installation, operation,

Fig. 3. Details make a difference.

and maintenance. Below are three examples of the effect of design, chosen because they are frequently ignored.

Installation

A better, lower cost installation will result if the mixer is designed to be an integral unit, an assembly that requires the least amount of job site work. The "mixer" of Figure 1 may have "cost" less than the mixer of Figure 2, but the chances are that it will be the more expensive to get on the tank and ready to run.

It is difficult to plan, estimate, and schedule an installation when the erection crew must assemble the equipment. They are likely to be unfamiliar with it. This is the expensive way, although the job site costs may be hidden by accounting practices. The price of the equipment is not its cost. The true cost is what it takes to get the equipment into its intended place and ready to work. "Push button" cost is one way of describing it.

Where tank and nozzle size is set, details like impeller diameter and construction can lead to expensive, embarrassing situations. If a large diameter turbine is specified as a one-piece casting, a large opening in the tank is necessary to get it in. The predicament in Figure 3 doesn't always happen to the other fellow.

For alloy tanks nozzle cost goes up rapidly with nozzle size. If a large turbine is designed with removable blades, it can fit through a small opening. Blades are replaceable when needed.

A mixer turbine 60 in. in diameter made as shown in Figure 4 will pass through a 22½-in. opening. Turbines 72 in. in diameter have been made in three sections to pass through a 20-in. opening.

Operation

Side-entering mixers are mounted so that shaft and stuffing box are below normal liquid level. For good stuffing box operation without too much leakage, shaft run-out must be limited. If the shaft design is based on service stresses alone, it will deflect too much at the stuffing box and batter an opening in the packing. Reducing leakage will be difficult. We have found that shaft static deflection at the stuffing box must be less than 0.005 in. to get good service from the stuffing box.

Figure 5 shows a 25 hp. unit with a mixer shaft which runs at 420 rev./min. To transmit the power, a 1½ in. diameter shaft would be all right, but to control the deflection for good stuffing box performance a 2½in. diameter shaft must be used.

Maintenance

A lot of complaining is done about stuffing boxes leaking too much and

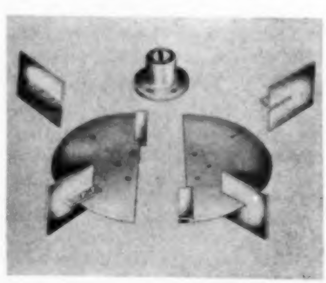


Fig. 4. Split type flat blade turbine.

being a maintenance problem. Good stuffing box performance depends on design; but just as important is its care. If the stuffing box design doesn't make it easy to adjust the gland, and repack the box, maintenance men won't take care of it.

Some design details are small things, take packing separators. They are shown between the rings of packing and above and below the lantern ring in Figure 6. Packing separators help to get better performance from stuffing boxes. They give lower stuffing box temperatures, but there are two simple maintenance reasons for using them.

1. Separators keep the rings of packing from sticking together making it easier to take the old packing out.
2. By putting packing separators above and below the lantern ring, lantern ring puller holes are kept from plugging.

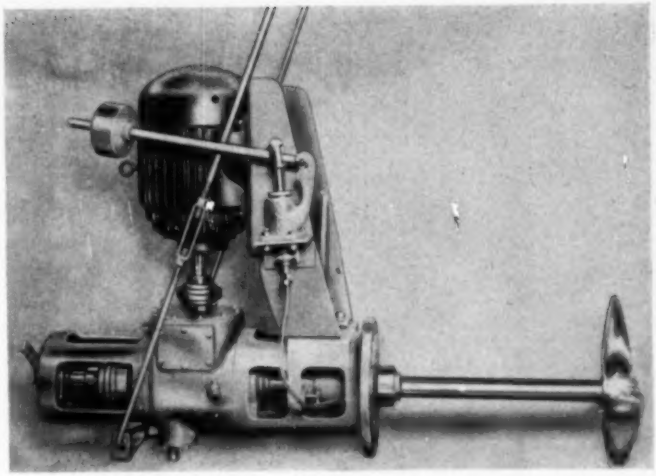


Fig. 5. 25 hp. side entering mixer.

Installation

Plan the Installation. It is more efficient to make a complete outline, planning the work from receipt of the mixer to the "push button point" than to have the man at the job site try to find something he needs and doesn't have. It isn't often that mixer installation is planned in detail. Trial will soon convince engineers of the wisdom of this procedure.

Make a Layout. Locate the mixer on the tank, see if there is enough room. Don't crowd the mixer since space is needed for maintenance. The more space there is, the easier maintenance will be. Figure 7 is an example of a good installation.

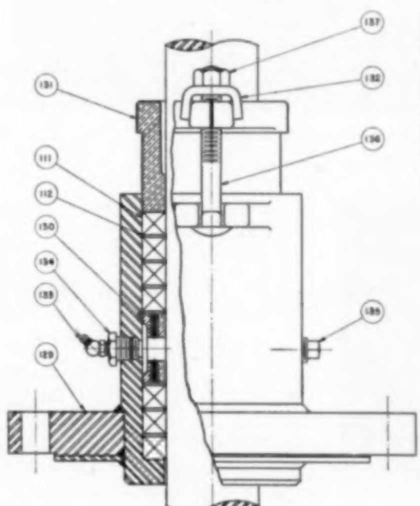
Tanks should be under a beam or hoist rail for ease in handling parts. Not long ago, to get a mixer in place a large company had to remove a section of roof. The mixer is in a crowded place and maintenance men don't give it proper care.

You can't always design an ideal setup. A mixer might have to be put on a tank which isn't strong enough. Mixer weight may have to be carried on a saddle spread over the tank shell, with a separate stuffing box. This means separate alignment of parts on the job which is not easy. Stuffing box and mixer shaft must be aligned, and if the shaft is long enough to need a steady bearing, the whole assembly must be carefully aligned.

Figure 8 shows a mixer mounted on an aluminum tank with a saddle to carry the mixer weight and a separate stuffing box. A steady bearing was eliminated by using a stabilizer * on the turbine, Figure 9. In this plant, the engineers and installation crew planned the installation carefully. The aluminum mixer shaft is $2\frac{1}{2}$ in. in diameter, with an 11 ft.-6 in. overhang. The shaft will bend if picked up in the middle, and must be handled carefully since a bend in the shaft will mean run-out, a leaky stuffing box, or lead to fatigue failure. An integral top entering mixer on a closed tank, is best for it gives alignment of all parts.

A closed tank mixer will be carried on a nozzle mounted in the tank head. If the tank is large and designed for low pressures, a reinforced head may be needed for a good mounting. Mixer mounting is important because the method of calculating the critical speed of the unit assumes a rigid mounting. The critical speed is the revolutions per minute of the mixer shaft equal to the natural frequency of vibration of the shaft. If the mixer is operated at this speed in air, the shaft will vibrate and, theoretically, will deflect infinitely. Long before it gets to infinity, it will be bent, broken, or go through the side of the tank.

A top entering mixer mounted on an open tank, must have beams strong enough to do the job. To avoid trouble from vibration, mount the mixer as rig-



ITEM NO	PART NAME
137	ADJUSTING NUT
136	BOLT
135	RELIEF PLUG
134	BUSHING
133	ALEMITE GREASE FITTING
132	GLAND CLAMP
131	PACKING GLAND - SPLIT
130	LANTERN RING
129	HUB & FLANGE ASSEMBLY
112	PACKING SEPARATOR
111	PACKING

Fig. 6. Typical stuffing box assembly.

* U. S. Patent 2195092.

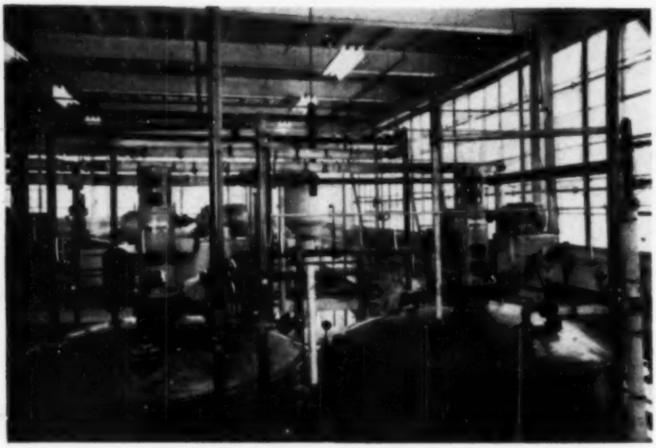


Fig. 7. Well planned installation.

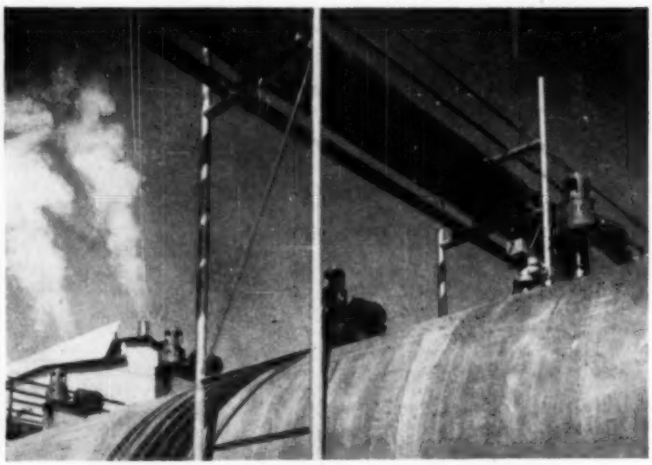


Fig. 8. Mixers mounted for tank load distribution.

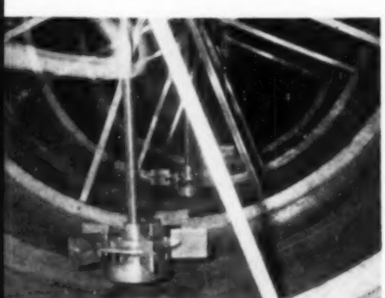


Fig. 9. Overhung shaft and turbine assembly of aluminum.

idly as possible. Brace beams laterally, particularly I beams. Where small mixers are mounted on tanks without a rigid support, it is important to make electrical connections flexible. There are two reasons for this:

Vibration may cause a fatigue failure of the electrical conduit.

There have been cases where the rigidity of the electrical conduit changed the critical speed of the assembly and brought it so close to the operating speed that the mixer shaft failed.

For top entering and side entering mixers mounted angularly and off center, it is important to have the tank strong enough so the mixer position won't shift and destroy the proper flow pattern which depends so much on the mixer position.

Side entering mixers are usually installed in large tanks which are under low pressure. On large tanks, mounting the mixer on the tank shell is like mounting it on a large flat plate.

Recently a petroleum refinery engineer complained that a mixer which had done a good job of gasoline blending in two hours was not doing the job in twenty-four hours. The plant engineer was sure that the mixer had been installed properly, angularly off center, and that the manufacturer's instructions had been followed. A topside inspection of the tank showed that the shell had buckled and the mixer position changed so that the mixer shaft pointed to the center of the tank. This shift in position changed the flow pattern in the tank to a swirling pattern with little mixing. As soon as the mixer position was corrected, it gave the same results as before. The tank shell should have been reinforced to prevent buckling where the mixer was mounted.

Figure 10 shows a mounting which is both good and bad. Good because the tank shell has been reinforced to keep the mixer in position; bad because the mixer is supported from two independent places. It's supported from the nozzle at the tank and by legs from a concrete block in the ground. When the tank is filled, there will be some settling; but the block won't settle. This will cause the mixer shaft to bind in the mixer bearings.

As another example: a side entering mixer which ran well when the tank was half full was 50% overloaded when the tank was filled. The overload was caused by the mixer shaft binding in the mixer bearings as the tank shifted from the weight of the additional liquid. The mixer should have been supported entirely from the tank.

Figure 11 shows a side entering mixer completely supported from the tank so that if the tank shell shifts, the mixer will go with it and stresses will not be set up in the mixer parts. The thrust of a side entering mixer propeller has to be carried by the nozzle and the tank wall on which the mixer is mounted. For 25 hp. side entering mixers running at 420 rev./min. this thrust is as high as 850 pounds.

Estimate the Installation. Make an estimate of the material and labor required. Do not leave "small" parts out. Talk to the men who have done similar jobs before. Get their ideas on how you can plan the next one. Make a form and list tools, handling equipment, welding equipment, and supplies which will be needed. Have any gaskets and packing

cut and formed so that it doesn't have to be done on the job. Schedule the different trades which you will need for the installation. Make your men's time effective by planning it.

Mixer Shafts. Good mixer performance depends on a straight mixer shaft. A top entering mixer shaft 2 in. in diameter, 10 ft. long, should be straight throughout its length to within 0.010 in. total indicated run-out. It is easy to bend a shaft, and most mixer shafts are bent in handling; few are bent in service. Don't pick up a long shaft in the middle. A shaft must be picked up at several points. Don't store the shaft standing up; but support it at more than one point. Protect the shaft surfaces that will run in the stuffing box and in bearings. Wrap with a tape, and keep wrapped until the very last minute. If the shaft has couplings, protect the coupling faces until they are ready to be bolted together. This will save a lot of filing and scraping on the job to get rid of burrs and nicks.

When the shaft is to be over 10 ft. or 12 ft. long, do not try to use one shaft in place of shorter coupled sections. The longer shaft will be harder to handle, more likely to be damaged in transit and in installation. In the long run, shorter, coupled sections will prove less costly and more convenient.

Stuffing Boxes. Stuffing boxes that aren't part of the mixer must be aligned carefully. If they are not in line with the shaft, it will force a larger hole in the packing and the stuffing box will leak. It is not an easy job to put a separate stuffing box on a tank and have it aligned with the mixer shaft. One way to do it is to mount the mixer, install and couple the shaft with the stuffing box on it. Use the shaft itself to get the alignment of the stuffing box assembly while it is welded or fastened to the tank. Have some means for fine adjustment after final installation—like shimming the mixer mounting. A stuffing box assembly welded to the tank isn't as good as one bolted to a nozzle. The mixer mounting or tank head may shift after a while. It is far better to have the stuffing box an integral part of the mixer.

Pack the stuffing box carefully. If you can use die-molded packing rings, you will get better service in the first hours

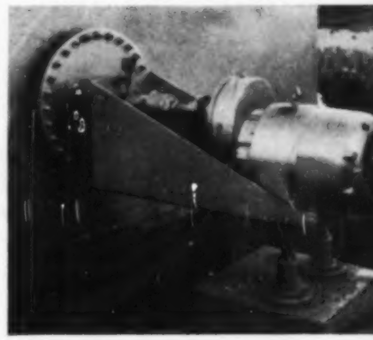


Fig. 10. Side entering mixer with pipe leg supports.

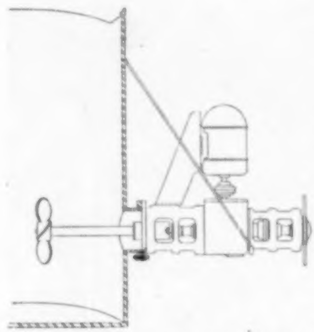


Fig. 11. Tank-mounted side entering mixer.

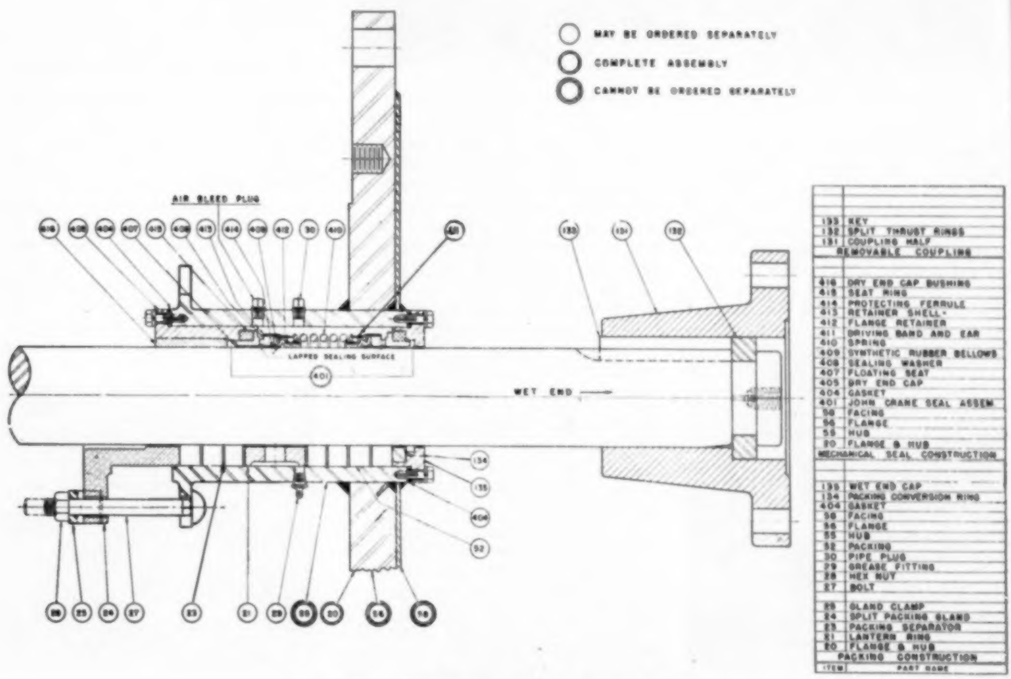


Fig. 12. Convertible top entering stuffing box—seals to packing.

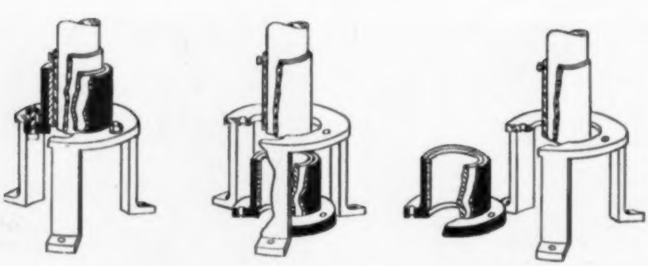


Fig. 13. This steady bearing assembly is easy to service.

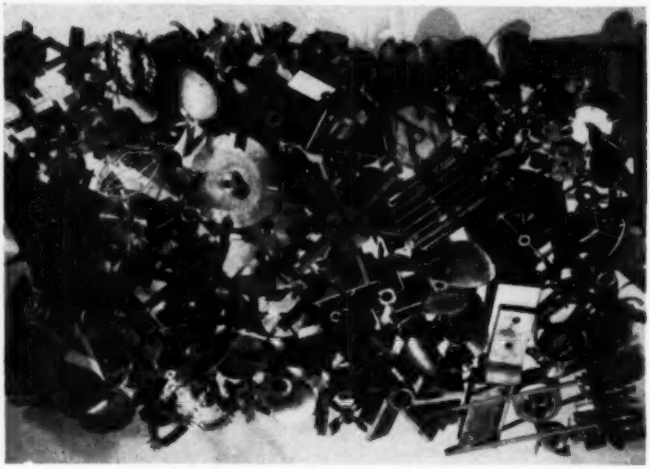


Fig. 14. What'll you have?

of operation. Seat each ring of packing separately and carefully. Use packing separators between the rings of packing, and above and below the lantern ring. Figure 6 shows a well-designed stuffing box. The stuffing box must be packed with the parts in the right order. If the wrong number of rings of packing is put in, the lantern ring may not be at the lubricant entry and the stuffing box will not get good lubrication.

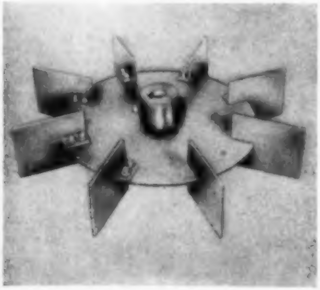


Fig. 15. Flat blade turbine.

With a single or double mechanical seal, alignment is critical. Some mechanical seals will not give satisfactory service if the misalignment of shaft and stuffing box exceeds 0.005 in. It is difficult to get good results with mechanical seals where the stuffing box is separate and not a part of the mixer assembly. If you can avoid it, don't use mechanical seals in a separate stuffing box.

Figure 12 shows a top entering stuffing box with a double mechanical seal. Because the stuffing box is above the liquid level in the tank, a double seal has to be used so liquid may be put in the space between the seals to lubricate and cool. It is important when installing such a stuffing box, to get all of the air out of the seal cavity so that the liquid will be above the sealing face of the upper seal. The liquid pressure in the stuffing box cavity must be at least equal to the pressure in the tank or 10 to 15 lbs. sq. in. higher.

The mechanically sealed stuffing box of Figure 12 is designed so packing can be used in the same assembly if the seal fails and you don't have a spare. Keep convenient the packing and parts to convert the mechanically sealed stuffing box. Emergency parts do no good if they are not found.

Mixer Mounting. If handling means are convenient, mounting of an integral mixer is easy. When ready to be hoisted, sling it so that it is level as it is lifted. Figure 2 shows this. This will save a lot of pushing and tugging. Forcing a mixer into position may damage shafts, stuffing boxes, and other parts. After mounting and assembly check alignment of all couplings, and finally, turn the input shaft by hand to see that it is free. Numerous times someone has forgotten to take a ladder, or a tool out of the way.

Steady Bearings. If the mixer shaft is so long that a steady bearing is needed, don't use a design where the mixer shaft must be taken out to change the bearing sleeve. The steady bearing should be mounted on a support fastened to the tank bottom or sides, but fixed so that the steady bearing assembly can be adjusted to be aligned with the mixer shaft. After alignment dowel it to its support.

Figure 13 shows a steady bearing assembly designed so that you can change the bearing without moving the mixer shaft. There is a replaceable wear sleeve on the mixer shaft.

Turbines, and Other Impellers

There are many things which influence the choice of the impeller. A great many different designs have been checked for power response and viscosity response. Figure 14 shows a few. Generally, you can do with one impeller what you can do with any other, if you know enough about their characteristics. On many jobs the mechanical design sets the impeller type. Often the size of opening in an existing tank, fittings inside the tank, and the physical characteristics of the material being mixed

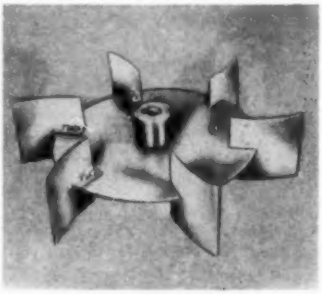


Fig. 16. Curved blade turbine.

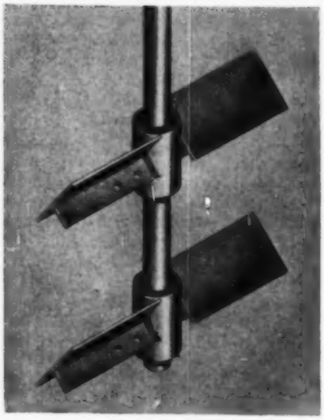


Fig. 17. Flat blade pitched paddle.

rather than the process determine the type and size of impeller.

Fabricated impellers usually will be more useful than cast impellers, except for propellers. They should be demountable to get them through small openings. The flat blade turbine, Figure 15, has excellent fluid dynamic characteristics and it is a practical design. Because the blades are bolted on, the turbine goes through an opening the size of the disk. Power is varied easily by changing the number and size of blades. Blades are replaced quickly and at low cost. This design is easy to modify; Figure 4. For abrasives or slurries, the curved blade turbine, Figure 16, is useful. Starting torque is less than that of the flat blade turbine and the blades don't wear as rapidly.

Flat paddles are used for slower speeds than turbines and they do a good job. Pitched paddles, Figure 17, or flat paddles, do not transmit power smoothly to the liquid. A long shaft with a paddle on it will tend to weave in the liquid because the load is not uniform. If this condition is severe, it may cause a fatigue failure of the shaft. A multi-bladed turbine transmits power more smoothly. In practice, never use a turbine with less than four blades at speeds above 50 rev./min. and avoid running paddles over this speed.

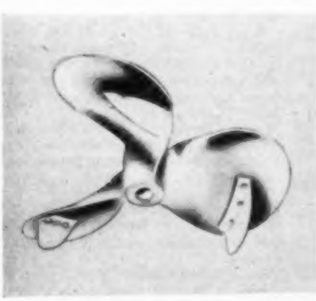


Fig. 19. Propeller with stabilizing ring.

For an agitated tank in a continuous system, with high throughput, use impellers which are stable and transmit power smoothly.

Shaft Vibration

Most mechanical trouble with mixers comes from shaft vibration. Shaft vibration can cause:

Fatigue failure of the shaft.

Damage to the mixer drive if the shaft is not isolated from the drive by a flexible coupling.

Damage to the stuffing box causing: Too much leakage through a packed stuffing box or failure of a mechanical seal.

Vibrations because of critical speed occur when the mixer is running in air. As soon as the liquid in the tank covers the bottom impeller without vortexing the liquid damps the vibrations. Because many things influence critical speed no mixer should be run within 20% of the calculated critical speed.

Make the mounting for a mixer strong. A sound, solid mounting is most important since incorrect mounting also can cause an alteration in the critical speed ratio of the assembly.

During draw-off and filling of a tank, don't run the mixer at speeds between 40% and 80% of the air critical speed without a steady bearing or a stabilizer, Figure 18. It will not run without dangerous and probably destructive vibrations. If your job requires a mixer to run during draw-off and filling, and you need a long shaft there are only three ways that this can be done.

1. Choose a speed for the mixer so that it does not run faster than 40% of its air critical speed.
   This isn't always possible since for long shafts the shaft diameter may have to be too great to be economical, or the speed may not be practicable.
2. Use a steady bearing.
   This has the effect of increasing the critical speed and it steadies the shaft.
3. Put a stabilizer under the bottom impeller.
   Figure 9 shows where a steady bearing could not be used and a long overhung shaft was needed so that the mixer could run at the lowest possible liquid level. To make it worse, everything in contact with the contents had to be aluminum. By analysis of the critical speed and using a stabilizer under the turbine, this 5 hp. mixer running at 90 rev./min. with a 2½-in. diameter aluminum shaft overhung 11 ft. 6 in. ran perfectly at all liquid levels.

Quite often, because a process is to be continuous and the mixer will not be running during draw-off and filling, a stabilizer or steady bearing will not be specified. There is no reason to take such a chance. If the mixer and tank are of alloy construction, or glass-coated, the value of a stabilizer or steady bearing as a safety precaution is obvious.

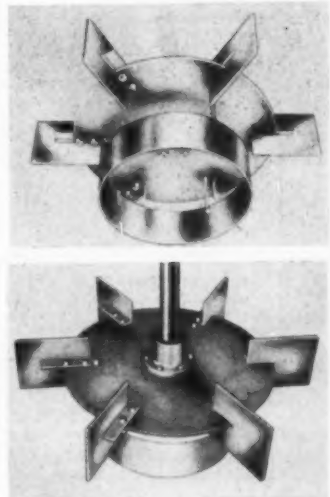


Fig. 18. Flat blade turbine with stabilizing ring.

Stabilizers are only effective when they are mounted under the bottom impeller so that they are the first thing to enter the liquid and the last to leave it. Stabilizers are effective with all impeller types. Fins, Figure 19, are just as good for propellers smaller than 18 in. in diameter.

Generally unless the mixer is going to run over 2000 rev./min., you won't need to balance the impeller and shaft assembly dynamically, a static balance is enough.

Propellers

The flat or slightly concave surface of a propeller blade, depending on the

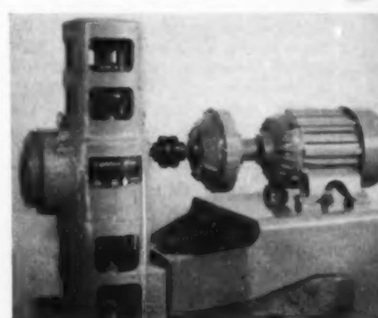


Fig. 20. Top entering mixer with fluid coupling drive.

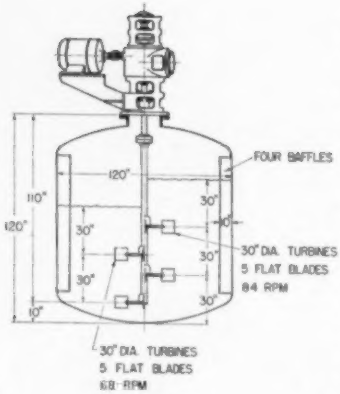


Fig. 21.

design, is the driving face; the convex face is the back. If the propeller is threaded on the shaft, be sure that you have some way of locking it on. The engineers of a large plant couldn't understand why the motor of a 25 hp. mixer drew no more current when the tank was full than when it was empty. They had started the mixer backwards and the propeller spun off and was on the bottom of the tank.

Operation

A sound rule of practice is to insist that the mixer be rotated by hand before it is started. This is a sure way to find out if there is any obstruction in the tank. Also, the operator should be able to feel binding caused by a change in alignment of the parts, a stuffing box which is too tight, or a rough bearing.

Before the mixer is started the first time, be sure that the motor is connected to the proper electrical supply and that the rotation is correct.

If the mixer is on a gas dispersion operation and sized to run during gassing only, some interlocking means should be provided so the mixer can't be started unless the gas is on. If the mixer is run when the gas is not flowing, the consequent overload may burn out the motor.

Solids settling out in the tank and covering the impeller may cause an overload. Figure 20 shows a mixer which has a fluid coupling between the motor and the speed reducer. This is an excellent way to protect the unit from heavy shock loads which would otherwise burn out the motor or damage the mixer.

There have been much published data on power characteristics of impellers. In spite of this, some engineers will make a change in an installation from the original design specifications without realizing how serious an effect these changes will have. For example, Figure 21 is a composite drawing showing on the left side the basis on which the mixer was selected, the right side shows the eventual installation. If the turbine positions and liquid level are changed, as shown on the right, these alone will have the effect of increasing the power to drive the mixer by 12%. The relative position of the impellers and the liquid coverage of the upper impeller have pronounced effects on the power. If the speed is raised from 68 rev./min. to 84 rev./min., this speed change alone would increase the power 90%. If both changes were made, the power required would increase about 102%. On the face of it, the changes themselves don't seem to be important, but the 102% increase in power is serious. When you have a mixer like the one shown in Figure 22, which has a variable speed drive, be especially careful that changes do not overload the motor. With pilot plant variable speed mixers it is common to try various impellers over a range of speeds. A good deal of care must be taken to prevent damage to the mixer by running an impeller combination at too high a speed. A change in viscosity will not have so pronounced an effect when the Reynolds number of the installation is above 5000. Any change in specific gravity of the liquid when the Reynolds number is over 5000 will bring about a proportionate change in power.

If a mixer is running in an unbaffled tank with liquid viscosity below 5000 centipoises, baffles in the tank will increase the power greatly. It is possible, by adding baffles, to increase the power drawn by the shaft and impeller assembly five times or more. Don't put baffles or tank fittings in an existing installation until you have determined the effect on the loading of the mixer.

In scaling up an operation for geometrically similar conditions, the horsepower varies as the fifth power of the impeller diameter when the same liquids are to be mixed. So, if you use a turbine geometrically similar but 20% greater in diameter, in the scaled up installation, it will draw 2½ times the power at the same speed.

A stuffing box which has been tightened too much, may also affect power demands. It is perfectly possible for the stuffing box of a mixer, which has a 2-in. diameter shaft operating at 420 rev./min., to be tightened so that 2 hp. or more is lost in the stuffing box itself.

Maintenance

The same principles which make for good maintenance of any machine apply to mixers. It is hard to tell whether bearings fail more from too much lubrication than from a complete lack of maintenance. A maintenance program means more than using the right lubricant at the right time. It also means using the right quantity of the right lubricant at the right time. Equipment and methods used for lubrication must be clean. Bearing failures have been traced to the fact that foreign matter got into the bearing with the lubricant.

By using a mixer maintenance record, like Figure 23, a maintenance program can be checked. For bearings, it is rare that conditions justify filling them more than one-quarter full of grease. Too much grease causes overheating and may lead to premature failure of the bearing and only means that, in time, there will be grease leakage at the oil seals.

Where sealed bearings are used, some grease leakage may appear after the unit has run a short time. If the leakage continues, it is a sign that the seal is defective.

Besides a lubrication schedule, there should be an inspection schedule. This list should include:

1. Checking the motor electrically for grounds and current leakage.
2. Checking the drive assembly.
3. Checking the condition of all bearings.
4. Checking flexible couplings for both angular and parallel alignment.
5. Checking the condition of the speed reducer gearing. Any sign of corrosion in the speed reducer may be due to:
   - (a) Moisture in the gear case, which can come from
     - (1) Water in the lubricating oil
     - (2) Condensation of the atmosphere in the gear case
   - (b) An acid condition in the lubricating oil.
6. Checking the assembly for corrosion.

Parts such as bearing mounting lock nuts, shafts, and other exposed parts outside the tank, should be protected from corrosion by covering them with an anticorrosion compound or painting them.

No matter how well designed the stuffing box of a mixer is, the results depend on care.

1. Don't tighten the gland any more than you have to.

   Taking up on the gland too much causes an unnecessary waste of power. Too much compression by the gland will cut down packing life and will cause the packing to wear the shaft faster than it should.
2. Keeping the gland level all the time is important if you want the least leakage with a minimum power loss in the stuffing box.

   A simple way to make sure that the gland is level is to use calipers between the upper face of the stuffing box hub and the under face of the gland.
3. Provide lubrication at the lantern ring continuously and, unless there are wide variations of pressure in the tank, at constant pressure.

The mixer in Figure 22 has a weight-loaded lubricator which does this. Notice the leak detector pan around the stuffing box. This leak detector pan is filled with liquid so the operator can detect any gas leakage from the tank. Where the gas in the tank is hazardous, this is a simple and effective detector.

If lubricating the stuffing box intermittently through a grease fitting, be sure that the relief plug opposite the fitting is taken out so the stuffing box will not be overfilled. Figure 24 is typical of the lubrication that most stuffing boxes get.

For any stuffing box to seal effectively, there should be a continuous liquid film between the stationary element and the rotating element. In the case of side entering mixers, the liquid in the tank very often provides enough lubrication for the packing and forms this film. If the material in the tank should not leak out, a lubricator supplying constant pressure to the lantern ring is useful. For top entering mixers, where the stuffing box is not in contact with the liquid, the stuffing box lubricant must supply the liquid film.

When the packing has been compressed to about three-quarters of its original volume, instead of adding a fresh ring or so of packing to the outboard end of the stuffing box, have the stuffing box completely repacked. If you use die-molded rings of packing, you will find that repacking is easier and you will get better results in the first hours of operation. When you repack a mixer stuffing box, follow these steps.

1. Clean the stuffing box. Flush out old lubricant. Don't repack if the shaft is badly scored or damaged. Make sure that the shaft and stuffing box are in alignment, and that the shaft surface is in good condition and highly polished.
2. If you are using bulk packing, cut it to the correct size carefully.
3. Put the packing, packing separator, and lantern ring in the stuffing box in the right order. Be sure to seat each ring of packing separately and carefully before putting in the next ring of packing.
4. The packing separators above and below the lantern ring keep the lantern ring puller holes from getting plugged.
5. After repacking, take out the relief plug and lubricate the stuffing box until the lubricant shows at the relief hole. Replace the relief plug and apply just enough pressure on the grease gun to distribute the lubricant without adding more.
6. If possible, run the mixer with the packing gland nuts only finger tight until the stuffing box has reached its highest temperature. Then stop the mixer, tighten the gland adjusting nuts with a wrench. Tighten carefully to keep the gland level. Doing this seats the packing while it is warm and plastic. Loosen the gland adjusting nuts so they are only finger tight and run the mixer. This procedure for reseating the packing will give you the best results.

If your operation prevents you from following this method, then be sure that the gland is not overtightened when it is adjusted with the mixer running.

For top notch stuffing box performance get the stuffing box temperature as a convenient and practical indicator of the stuffing box condition. This can be done by attaching a thermocouple lead to the stuffing box hub, or taping a thermometer to the stuffing box hub.

There are so many ways that an overhung mixer shaft can be damaged in service, that it is a wise precaution to schedule periodic inspection of the shaft and impeller assembly to check for

1. Corrosion or abrasion
2. Shaft straightness
3. Tightness of fastenings
4. Bent impeller blades or stabilizers

Where the mixer has a steady bearing, it is most important to practice preventive maintenance so that the bearing does not fail in service. If the steady bearing loses its effectiveness, the shaft assembly behaves as though it were an overhung mounting. The steady bearing was put in because the overhung mounting would not do.

If a steady bearing is used on a mixer shaft, and the liquid in the tank has abrasives, piping a clear liquid to flush and lubricate the steady bearing will extend its life.

(The articles on Maintenance in this issue and in the February, March, and April issues, were adapted from a Symposium on Maintenance held at the Rochester meeting. D. A. Pierce was its chairman.)

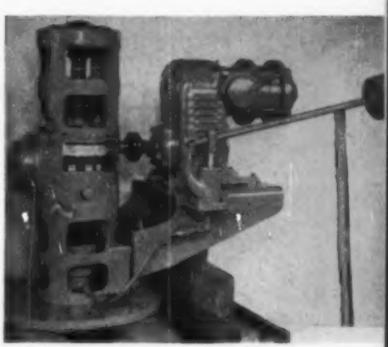


Fig. 22. Variable speed top entering mixer; stuffing box equipped with weight-loaded lubricator and leak detector pan.

MIXER MAINTENANCE RECORD

Mixer ________ Model ________ Mfg. ________

Location ________ Serial No. ________

Motor H. P. ________ Motor RPM ________ Mixer RPM ________ P. O. ________ Date ________

Reference Drawings ________

INSPECTION SCHEDULE					LUBRICATION SCHEDULE					
Item	Description	Interval	Date Inspected	By	Lubricate	Lubricant	Amt.	Interval	Date	By

MAINTENANCE

Date	Job Number	Description	By	Labor Man Hours	Material Cost

SEE OVER FOR SPARE PARTS LIST

Fig. 23.

Fig. 24. Anything but this!

GASEOUS FLUIDIZATION OF SOLID PARTICLES

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University of Illinois, Urbana, Illinois

A theory of fluidization is developed which is based on the forces and energy transformations existing within a fluidized system. The system is assumed to attain the most stable configuration, and the particles are shown to be at their terminal velocities. From these considerations the average Reynolds number in the dense or continuous phase is essentially independent of the superficial gas velocity. An analysis of the energy transformations results in a general equation relating the pressure drop to the superficial gas velocity and the particle diameter. The gas flow through the interstices of the bed, both at incipient fluidization and at higher velocities, can be estimated. Differential pressure losses through fluidized beds of spherical beads and velocities of the particles along the wall were measured.

MOST of the theories and correlations that have been developed to explain the nature of fluidized beds are based on fixed bed relationships (*11, 15, 17*). While these may be a convenient starting point, they do not explain the true characteristics of fluidized beds, since the two systems are inherently different. A review of the literature shows that there is no satisfactory explanation of the mechanism of fluidization which is quantitatively supported by the available data. The present work was undertaken to study the motion within a fluidized system and the rate of heat transfer between the bed and boundary surfaces. The part of the work concerned with the theory of fluidization is presented here. Data on heat transfer and an analysis of flow patterns within the system will be published in a later paper.

Experimental

In all cases the fluidizing medium was filtered air, delivered to the system at about 200° F. and one per cent relative humidity. The air was metered through critical orifices. The solids used were commercial grades of Scotchlite glass beads obtained from the Minnesota Mining and Manufacturing Co. Table 1 lists the physical properties of the five sizes of beads used. The average diameter of each size was determined by measurement under a microscope, and the absolute particle density was found by measuring the water displacement of a known weight of beads.

A cross section of the column used is shown in Figure 1. It was formed by cementing together, one above the other, seven sections each 4.7 in. I.D. and 6 in. over-all height (see Fig. 2) and a top section of the same diameter and 20 in. high. Both the sections and prisms are numbered from the bottom. The design of the column was dictated primarily by the requirements of the heat-transfer measurements. All the internal equipment was supported from the upper plate and could be raised above the level of the bed when not in use. This included a ½-in. Calrod heater in the center of the bed which remained in place during all the measurements, and a special tube with taps to measure the pressure drop across each of the individual sections. The exit gases passed through a cyclone, and the solids thus collected were intermittently returned to the fluidized bed.

Glass prisms were inserted between the metal sections with the inside face flush with the wall of the column (Fig. 2), so that an accurate measurement of the particle velocity could be made simultaneously with the pressure and heat-transfer measurements. A 16-mm. Western Electric Fastax high speed motion-picture camera was used for photographing the moving bed through one face of the prism while a lens system focused a light through the other face. The film was later examined and a plot of particle velocity at the various levels against time was made.

Data concerning the controllable variables and pressure drops on each run are given in Table 2, while the data calculated from the motion picture film are recorded in Table 3. Duplicate measurements of pressure drop checked on the average within 2%. Measured velocities of the glass beads are accurate over the time interval during which they were photographed, but since this was rather short, an unknown error could be introduced by using these as average velocities.

Type of Gas Flow. The theory of fluidization postulated here is based on energy and force relationships within a fluid system rather than on comparisons with static beds. A fluidized bed is considered as composed of two phases: the first consisting of uniformly distributed particles in a supporting gas stream, and the second consisting of pure gas in the form of bubbles, channels, or slugs. The former phase is known as the continuous phase, while the latter is termed the discontinuous phase. The bed fluidizes when there is enough gas flow to support the continuous phase, while the discontinuous phase appears at all appreciably higher gas velocities. Incipient fluidization occurs when the particles are just suspended in the gas stream. Several investigators have described the bubbles in fluidized beds, but not in a quantitative manner (*6, 12, 13, 17*).

Before continuing, the limitations of the discussion should be emphasized. This paper is based on experimental evidence obtained from gas fluidization of particles within a limited range of sizes, and therefore all statements and conclusions are limited to these conditions. The relationships are developed for systems of uniform spheres; modifications may be necessary for appreciable deviations from such a system. Furthermore, no attempt is made to in-

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Table 1. Properties of Scotchlite Glass Beads

Bead Size No.	Manufacturer's Bead Size No.	Average Particle Diameter, in.	Average Particle Diameter, microns	Mean Deviation from Average Diameter %	Absolute Particle Density lb./cu.ft.	Maximum Void Fraction in a Fixed Bed
1	4	0.0334	848	17.2	175	0.368
2	8	0.0148	376	3.1	179	0.404
3	10	0.00862	219	6.4	178	0.420
4	13	0.00418	106	8.6	173	0.416
5	16	0.00215	55	20.7	167	0.392

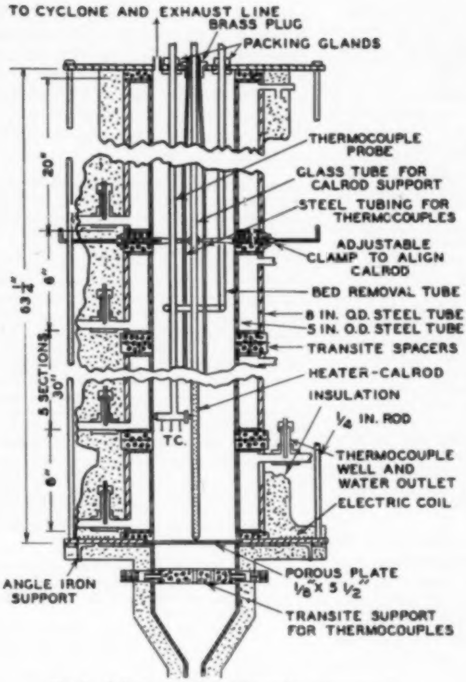

Fig. 1. Column used for heat-transfer measurements.

Table 2. Pressure Losses in Fluidized Beds

Bead Size No.	Diameter of Beads in.	Mass Velocity lb./(hr.)(ft.^{2})	ΔP_{mf} in. H_2O	Bed Height at Minimum Fluidization (in.)	$\frac{\Delta P_{ke}}{\Delta P_{mf}}$
1	0.0334	919	44.3	25.0	0.160
		716	44.3	25.0	0.068
		486	44.3	25.0	0.077
2	0.0148	1 542	23.9	14.0	0.092
		1 198	23.9	14.0	0.155
		968	23.9	14.0	0.166
		746	30.9	18.1	0.142
		742	23.9	14.0	0.084
		737	40.5	23.8	0.291
		737	35.7	21.0	0.241
		613	39.1	23.0	0.278
		442	40.5	23.8	0.220
		270	40.7	23.9	0.177
		141	41.0	24.1	0.084
3	0.00861	1 520	15.5	9.4	0.206
		1 342	19.9	12.0	
		1 199	17.4	10.5	0.189
		988	21.6	13.8	
		747	36.1	23.0	0.349
		743	31.4	19.0	0.131
		741	25.8	15.6	0.094
		745	21.8	13.2	0.046
		743	19.8	12.0	0.071
		345	40.7	24.6	0.243
		272	37.8	22.8	0.204
		196	41.1	24.8	0.151
		66.3	41.1	24.8	
		66.3	41.1	24.8	
		66.0	40.7	24.6	
		66.0	40.7	24.6	0.0541
4	0.00418	346	27.4	17.0	
		342	20.1	12.4	0.104
		201	27.4	17.0	0.179
		155	27.4	17.0	0.164
		127	27.4	17.0	0.135
		103	27.4	17.0	0.117
5	0.00215	197	38.0	23.4	
		123	39.3	24.2	
		70.3	39.6	24.3	
		40.1	39.4	24.3	
		23.7	39.4	24.3	

terpret the effect of varying the properties of the gas or solid.

First, it is desirable to examine the type of gas flow in the continuous phase. Several indications can be found which show that the local gas flow within the continuous phase is laminar, or viscous. Chilton and Colburn (*5*) correlated the data available on the flow of fluids through fixed beds of granular solids, and found that the transition between viscous and turbulent flow occurs at a Reynolds number $(D_p u_f \rho_g/\mu_g)$ of about 40. For the velocity at incipient fluidization, the Reynolds number for the fixed beds of the glass beads used in this work were 0.014, 0.095, 0.55, 2.88, and 12.2. Since a slight separation of the particles should not appreciably increase the tendency to produce turbulence, the gas flow around the particles should always be viscous. Visual observation of fluidized beds readily shows that, as the gas velocity is increased, most of the additional gas, after incipient fluidization, passes through the bed as the discontinuous phase and therefore does not appreciably affect the quantity of gas flowing through the continuous phase. Later it will be shown that, for any over-all gas velocity, the Reynolds number based on the superficial velocity past the particles in the continuous phase varies only slightly from that at incipient fluidization. If this is true, then there is little opportunity to pass from viscous to turbulent gas flow in a fluidized bed as the superficial gas velocity is increased.

There is other evidence to support this contention. Morse (*15*) replotted the data of Wilhelm and Kwauk (*17*), and of Leva (*10, 11*), using the dimensionless groups proposed by Blake (*2*), and in almost every case obtained a straight line, showing that if the gas flow at incipient fluidization is viscous, it probably does not reach turbulent flow at higher superficial velocities. With a similar plot based on the velocity of the particles with respect to the wall instead of the superficial air velocity, the same conclusions may be drawn from data taken in the present work. Kettenring, Manderfield, and Smith (*9*) found that the heat- and mass-transfer coefficients between the solids and the gas stream are considerably lower in fluidized beds than in packed beds at the same superficial velocity. Gamson (*7*) found it particularly interesting to observe that the normal flow in the absence of particles for the heat-transfer data of Mickley and Trilling (*14*) would cover viscous, transition, and highly turbulent flow, whereas his recommended correlations in the presence of particles showed no breaks or transitions over the range of modified Reynolds numbers studied. From these observations, the assumption of viscous flow in these fluidized systems is reasonable. The generalization to all types of fluidization, however, need not be made. While some of the subsequent considerations are based on this assumption, they do not necessarily depend on viscous flow in the continuous phase. The term "viscous" is used here in contrast to turbulent flow, and applies only to the flow of gas in the continuous phase. Local conditions of gas flow, such as at gas inlets and at the phase boundaries, may of course be turbulent.

Nature of Fluidized Beds. The absence of translational motion at the start of fluidization and its increase with increase in gas velocity is easily observed in a glass column. The formation of the discontinuous phase also follows this pattern. When the discontinuous phase forms at the gas inlet, it is acted on by a buoyant force due to its immersion in the denser phase. The movement of the discontinuous phase through the bed under the influence of the buoyant force is considered to be the cause of the translational motion of the particles within the bed. The particles near the discontinuous phase move upward with this phase while other portions of the continuous phase move downward. Thus the whole system is set in motion, the degree of which depends primarily on the volume of the discontinuous phase passing through the bed. At incipient fluidization, the gas velocity is just sufficient to maintain the solid particles suspended in the gas stream; hence the particles must be at a terminal velocity. Superimposed on this relationship at higher velocities is the bulk movement of the continuous phase due to the passage of the discontinuous phase. As this movement should not influence the relative movement of the gas past the particles, the particles are considered to be always at their terminal velocity. This concept does not depend on viscous flow.

The formation and expansion of a fluidized bed may now be examined in detail. When there is sufficient gas flowing to sustain the individual particles at their terminal velocities, incipient fluidization occurs. Assuming for the moment that only the continuous phase exists, an incremental increase in the superficial gas velocity would necessitate a slight expansion of the system. The system must expand until an equilibrium void space is established which

both maintains the particles at their terminal velocity and permits the additional gas to pass through the voids of the continuous phase. As the superficial gas velocity is increased, however, the flow through the bed would eventually tend to become turbulent. In other flow systems, increasing both the linear gas flow and the diameter of the openings ultimately produces turbulent flow. It is postulated, therefore, that the single-phase fluidization remains stable until a critical condition is reached, and then the system has the remarkable property of having all of the additional gas flow pass through the bed in the form of a discontinuous phase. Single-phase fluidization becomes unstable when the system no longer can fulfill the conditions for maintaining the particles at a terminal velocity while at the same time passing the additional gas. Possibly this is due to a change in the type of gas flow around the particles or to the character of the attractive forces between the particles. As long as the system can permit the additional increments of gas to pass as the discontinuous phase, the fraction void space and density of the continuous phase will be independent of the gas velocity. The state existing between a fixed bed and a fluidized bed of two phases has been described by Ergun and Orning (6) who found that two-phase fluidization of spheres begins when the void fraction exceeds about 0.46. Thus the average density of all continuous phases in the systems studied will be approximately equal.

Bowman (3) has presented a theoretical study of fluidization in which all of the forces in the fluidized system which act on the particles are taken into consideration. The resulting equation for aggregative fluidization indicates that the critical variables have a narrow range over which they may vary. This is similar to the concept of a critical condition which tends to maintain the density and gas flow within the continuous phase independent of the total superficial velocity when the discontinuous phase is present.

As the superficial gas velocity is increased, it becomes more difficult for the fluidized system to pass such large quantities of bubbles. The particle velocities increase and the particle motion becomes more random, thus tending to destroy the uniform continuous phase, especially at the interphase boundaries. The energy loss due to this movement will be described later. At these higher velocities an increasing number of particles are thrown into the region above the fluidized bed. Within the bed, the gas takes two paths: one through the continuous phase which supports the particles, and the other in the discontinuous phase. The particles thrown into the region above the bed are subjected to all the gas flowing, and if the gas velocity in the open tube is greater than the terminal velocity of the single particles they will be carried out of the system. At extreme velocities these conditions lead finally to disintegration of the fluidized system.

In summary, it may be stated that the forces within the continuous phase tend to maintain two distinct phases, each of constant properties, while the movement of the discontinuous phase tends to destroy this relationship. The particles are held together within the dense phase principally by the Bernoulli forces, as described previously by Wilhelm and Kwauk (17) and by Bowman (3). It is these forces, existing because of the changing flow areas and velocities within the bed, that are chiefly responsible for the attraction between the particles.

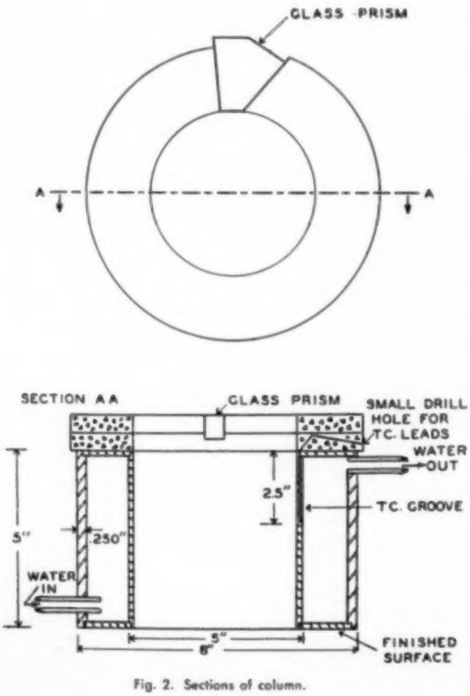

Fig. 2. Sections of column.

Energy Transformations Within Fluidized Systems. In order to fluidize a bed of solid particles it is necessary to maintain the pressure difference across the bed at least equivalent to the weight of the particles per unit area. An increase in the gas velocity will increase the pressure drop slightly, and this additional pressure drop will be defined as ΔP_{ke}, or the pressure drop due to kinetic energy losses. The passage of the discontinuous phase through the fluid bed produces translational motion of the particles. It is postulated that this motion causes collisions between the particles which dissipate as heat the energy due to ΔP_{ke}. In analyzing these energy losses, it is desirable to derive a relationship between ΔP_{ke} and the superficial gas velocity for any particle diameter. This derivation is based on the concepts of fluidization stated above and upon the following three considerations of the energy transformations within a fluidized system:

1. A relationship between D_p and the energy lost by particle collisions at a constant volumetric flow of the discontinuous phase.
2. The buoyant force at varying gas velocities for any given particle diameter.
3. The increased pressure drop of the fluidizing gas over ΔP_{mf}.

This approach to the problem was used, since a more direct mathematical approach yielded simultaneous partial differential equations in three unknowns that could not be solved.

First, the effect of particle diameter on the amount of energy dissipated will be determined under the condition of constant V_g, or volume of the discontinuous phase flowing per unit time. As the particles in the continuous phase are always at their terminal velocity, the drag force per unit volume of the continuous phase is always constant. Superimposed upon this force is a shearing force due to the movement of the discontinuous phase which causes adjacent strata within the system to move at different velocities. The particles will still remain at their terminal velocity under this force, but the slight changes in velocity from point to point will cause the rotation of the individual particles and collisions between adjacent particles.

Bingham (1) describes the collision of two spheres in a fluid field and states that the viscous resistance to the shearing action which two spheres set up as they approach each other will rapidly dissipate their energy of rotation as heat. For a given system and volume concentration, the number of collisions is proportional to the number of particles, which for spheres, varies in-

versely as the cube of the diameter. Bingham states also that, if the angular velocity is independent of the diameter, the energy of rotation will be proportional to D_p^2, and the loss of energy due to the collisions will be inversely proportional to the diameter. The system which he considers is similar to the continuous phase as previously described. The average angular velocity of the particles in a fluidized bed, however, is not independent of the particle diameter at constant V_g, as the angular velocity will be proportional to the velocity of the discontinuous phase. The velocity of the discontinuous phase through the bed may be shown from experimental evidence to be proportional to the square root of the particle diameter.

Lewis, Gilliland, and Bauer (*12*) found that the following empirical equation expresses the effect of particle size and gas velocity on the change in bed depth above that at incipient fluidization,

$$1 - \frac{L_{mf}}{L_f} = \frac{0.065}{D_p^{0.5}}\,(u_f - u_{mf}) \tag{1}$$

This may be rewritten as

$$\frac{V_b}{AL_f} = \frac{0.065}{D_p^{0.5}}\,(u_f - u_{mf}) \tag{2}$$

where V_b is the volume of the discontinuous phase in the system at a given time in contrast to V_g, the volume of the discontinuous phase flowing per unit time. Since

$$(u_f - u_{mf})A = V_g \tag{3}$$

it follows that the time of detention of the discontinuous phase within the bed is

$$t_d = \frac{V_b}{V_g} = \frac{0.065 L_f}{D_p^{0.5}} \tag{4}$$

Thus, L_f/t_d, the velocity of the discontinuous phase, is proportional to $D_p^{0.5}$.

If the angular velocity is independent of the particle diameter, the loss of energy of rotation is seen to be inversely proportional to the diameter. The dependence of the velocity of the discontinuous phase on $D_p^{0.5}$ will affect this relationship in two ways. First, as the bubbles rise faster they will move the particles correspondingly faster, and hence the number of collisions from this effect should increase as $D_p^{0.5}$. This was partially verified by the particle velocity measurements. Secondly, the velocity of the discontinuous phase would cause the angular velocity of the particles to vary as $D_p^{0.5}$ and, since the kinetic energy of rotation is proportional to the square of the angular velocity, this effect would cause the kinetic energy of rotation of the particles to vary directly as the particle diameter. The combination of these two effects with the original relationship noted by Bingham indicates that the kinetic energy loss at constant V_g is proportional to the square root of the particle diameter.

For small columns, an additional term is necessary because of the effect of the wall on the pressure drop. Therefore, the rotational energy loss, which is equal to the work done on the particles, becomes

$$W \sim (K'D_p^{0.5} - k') \tag{5}$$

Considering a fluidized system of given size particles, the work done by the discontinuous phase may be expressed in terms of the buoyant force acting through the bed height. For a differential increase in V_g,

$$dW \sim (\rho_m - \rho_g) L_f dV_g \tag{6}$$

Since the quantity of gas passing in the continuous phase is constant, and $V_g = V - V_v$, it follows that dV may be substituted for dV_g.

Two independent variables, the particle diameter and V_g, determine the additional energy needed to pass the discontinuous phase over that necessary to suspend the particles at incipient fluidization. Equations (5) and (6) show the relation of this energy to these quantities. Since the subsequent integration does not involve a variable particle diameter, the amount of work may be expressed as proportional to the product of these expressions.

$$W = (KD_p^{0.5} - k)(\rho_m - \rho_g) L_f \int_{V_v}^{v} dV \tag{7}$$

The limits of integration are from the inception of two-phase fluidization to any higher gas velocity.

The amount of work may also be expressed in another way. That part of the pressure drop which provides the additional energy is ΔP_{ke}. The energy

Table 3. Average Velocities of Particles at Wall and Corresponding Pressure Losses

Bead Size No.	Mass Velocity lb./(hr.)(sq.ft.)	u_p ft./sec.	$u_p/D_p^{0.5}$ ft.$^{0.5}$/sec.	$\Delta P_{ke}/L$ lbs./(sq.ft.)(ft.)
2	737	2.40	65.7	31.5
	613	2.46	67.4	28.5
	270	1.38	37.8	14.2
	141	0.28	7.67	2.98
3	747	1.84	68.5	34.7
	345	1.72	64.0	25.6
	272	1.4	55.0	22.7
	66	0.177	6.58	5.88
4	346	0.83	44.2	20.8
	201	0.71	37.8	17.2
	155	0.60	31.9	15.6
	127	0.77	41.0	14.3
	103	0.38	20.2	12.9

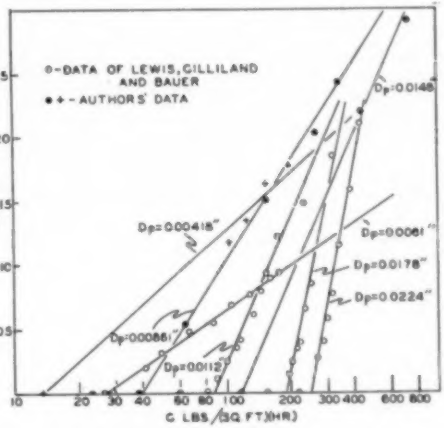

Fig 3. Kinetic energy losses in fluid beds.

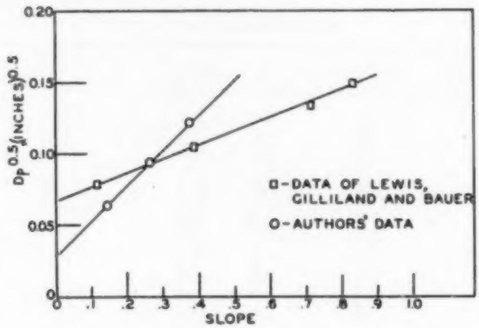

Fig. 4. Relation between slope of log $G - \Delta P_{ke}$ plot and D_p.

dissipated by the collisions of the particles therefore must be equal to the product of the volume of gas passing through the bed and the kinetic energy pressure drop.

$$W = V \int_0^{\Delta P_{ke}} d(\Delta P_{ke}) \qquad (8)$$

After setting Equations (*7*) and (8) equal, integration gives

$$\int_0^{P_{ke}} d(\Delta P_{ke}) = (KD_p^{0.5} - k)(\rho_m - \rho_g)L_f \int_{V_v}^{V} \frac{dV}{V} \qquad (9)$$

This becomes

$$\Delta P_{ke} = (KD_p^{0.5} - k)(\rho_m - \rho_g)L_f \ln \frac{V}{V_v} \qquad (10)$$

As ΔP_{mf} equals the weight of the bed per unit area, or approximately $(\rho_m - \rho_g)L_f$, Equation (10) may be expressed as a function of $\Delta P_{ke}/\Delta P_{mf}$, the fractional increase in pressure drop due to the kinetic energy loss,

$$\ln \frac{V}{V_v} = \frac{1}{(KD_p^{0.5} - k)} \frac{\Delta P_{ke}}{\Delta P_{mf}} \qquad (11)$$

The equation fits the experimental data well. Because of the difficulty in obtaining accurate values of ΔP_{ke}, data on beads No. 1 and 5 could not be used. Data on the other sizes, as well as those of Lewis and associates (*12*), are plotted in Figure 3. The average deviation from the best straight line for each size is only a few per cent. According to Equation (11), the intercept of the straight lines with the abscissa represents the superficial velocity in the continuous phase of two-phase fluidization. Only the data of Lewis, Gilliland and Bauer (*12*) extend to low enough velocities to obtain an accurate indication of the point of intersection. The points on the abscissa represent the superficial velocity at incipient fluidization as calculated from the data reported. For the four particle diameters, the ratio u_{mf}/u_v is 0.85, 0.69, 0.83, 0.87. Several points are available for the extrapolation at each velocity so that these values should be reasonably accurate. Thus, only a slight increase in gas velocity over that at incipient fluidization is needed to reach the critical condition where the discontinuous phase forms. Values of the ratio show no dependence on particle diameter. Data on the smallest particles used in both investigations were omitted because of inaccuracies in the measurement of the small pressure differences, and also because of the greater importance of attraction forces between the small particles.

The slopes of the straight lines in Figure 3, which are proportional to $(KD_p^{0.5} - k)$, are plotted in Figure 4 against $D_p^{0.5}$. The slopes from the two series of experiments fall on different straight lines, as would be expected, since the derivation does not take into consideration the effect of column area, gas entrance, shape of the bed, etc. The column used in the present work had a half-inch Calrod heater down the center, so that a comparison between the two columns is difficult. K is represented by the slopes of the lines in Figure 4, while k is the intersection of the lines with the ordinate. Lewis, Gilliland, and Bauer showed graphically that the fractional increase in pressure drop, $\Delta P_{ke}/\Delta P_{mf}$, decreases with increasing column diameter and decreasing bed depth. Thus it appears that the more freedom that the particles have due to a small wall area per unit volume, the less energy the continuous phase expends to pass the discontinuous phase. This graphical treatment of fluidization data appears to be a useful method for measuring the wall effect in a fluidized bed.

There are some limitations of Equation (11) which should be recognized. Theoretically, ΔP_{mf} should be equal to the pressure drop when the continuous phase is about to form, except for a slight change in the drag. Actually, there are two other conditions which tend to increase the pressure drop slightly at the inception of two-phase fluidization. The wall effect may cause rotation of some particles, which dissipates energy as the particles become further separated. Furthermore, there must be an expansion of the gas as the pressure changes through the bed. Both of these effects would cause the data in Figure 3 to show a slight curvature near the abscissa.

Comment

The concepts of a critical condition in the continuous phase and fluidized particles at a terminal velocity, if combined, present a useful set of relationships. Although not completely understood, the occurrence of similar relationships from several independent sources justifies their mention at this time. For viscous flow, the terminal velocity of a freely falling particle is given by

$$u_t = K \frac{(\rho_s - \rho_g)}{\rho_s} \frac{D_p^2}{\mu} \qquad (12)$$

where K has been shown to be reasonably constant in the range of Stokes' law for freely falling spheres at their terminal velocity.

The velocity of the gas past a particle in a fluidized bed is different from that past a single freely falling particle because of the proximity of other particles. Rouse (*16*) states that a solid boundary in the neighborhood of the relative motion will increase the deformation drag through transmitted shear, or will alter the pressure distribution when inertial effects are involved. In discussing the rate of settling of small particles of solid matter through liquids and gases, he shows that, in the case of deformation drag, the proximity of boundary surfaces will markedly augment the resistance. These effects may be taken into account through use of a correction factor determined analytically by Ladenburg; with slight modification of the second numerical term (*16*), this factor takes the form $(1 + 2.1D/L)$ for a sphere of diameter D moving along the axis of a cylinder of diameter L. It should be noted that the correction factor depends on the geometry of the system and that, if the ratio of the dimension of the opening to that of the particle is constant, the correction is a constant. If the per cent void space in the continuous phase is assumed to be constant, the ratio of pore opening to particle diameter is constant. As the correction factor accounts for the drag due to near-by boundary surfaces and as fluidized systems by their nature maintain the ratio of pore opening to particle diameter constant, the correction to Equation (12) should be constant and the relation between the critical variables as represented by Equation (12) should be valid.

It was postulated that single-phase fluidization remains stable until a critical condition was reached, and that at higher velocities the density of the continuous phase is independent of the superficial gas velocity. As the actual resistance encountered by an immersed body depends upon the Reynolds number

which characterizes the motion, and upon the shape and position of the body, this critical point possibly can be represented by a single Reynolds number. This Reynolds number must include the effective values of velocity and viscosity within the fluidized system and therefore it cannot be considered as the usual Reynolds number of a falling particle.

Equation (12) and the relationship represented by a constant Reynolds number both contain three variables; the particle diameter, a velocity, and a viscosity, and both apply to the same particles, or group of particles under the same flow conditions. It is reasonable to assume therefore that if the velocity and viscosity terms in each equation are not identical, at least they would be proportional to each other. If this assumption is made, then the following relationships hold

$$u_t \sim D_p^{0.5} \qquad (13)$$

$$\mu_e \sim D_p^{1.5} \qquad (14)$$

These relationships do not depend on the assumption of viscous flow. If the concept of a constant Reynolds number is combined with the equation for the terminal velocity in the intermediate region, or with the equation for the terminal velocity in turbulent motion, the same relationships are derived.

These proportionalities may be helpful in determining just what is represented by the effective or critical velocity and viscosity of a fluidized bed. Matheson, Herbst, and Holt (*13*) measured the viscosity of fluidized beds with a modified Stormer viscometer. Although the relationship between the observed viscosity and the effective viscosity is not obvious, it is interesting to note that the measured viscosities are approximately proportional to $D_p^{1.5}$.

A comparison can be made with colloidal solutions to substantiate further the dependence of viscosity upon the particle diameter. Hatschek (*8*) reports data on viscosities of concentrated suspensions which show that the viscosity increases much more rapidly than the volume fraction of the solids. Furthermore, at a given concentration of the solids, the viscosity increases as the diameter of the particles decreases. In his analysis of rotating spheres in a fluid medium at constant void fraction, Bingham (*1*) showed that, for constant angular velocity, the loss of energy should be inversely proportional to the diameter of the particles. He notes that this conclusion, if correct, is an indication that finely divided particles should give comparatively viscous suspensions. The consideration of spheres in a fluidized bed, however, showed that the loss in energy due to collisions increased with particle diameter. From these relationships, the viscosity in fluidized beds would be expected to increase with particle diameter.

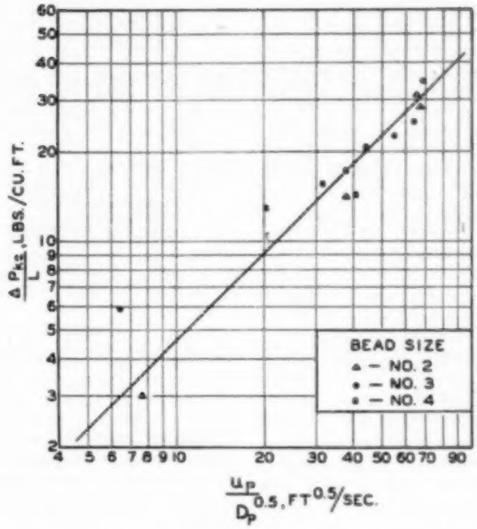

Fig. 5. Relationship between particle velocities and pressure loss.

There are several independent sources of evidence which indicate that the velocity associated with the continuous phase is proportional to the square root of the particle diameter. Equation (1), which was developed by Lewis, Gilliland, and Bauer to correlate their data, has been rearranged to show that the velocity of the discontinuous phase through the bed is proportional to the square root of the particle diameter. Particle velocities along the wall were measured primarily to aid in understanding the heat-transfer mechanism, but their relation to ΔP_{ke} are of interest here. The relationship between ΔP_{ke} and the particle velocities along the wall is shown in Figure 5, where $\Delta P_{ke}/L$ is plotted against $u_p/D_p^{0.5}$. Here again the square root of the particle diameter correlates the data on velocities within a fluidized system.

The interpretation of Equation (1) and the accuracy with which Equation (11) fits the available data support the original postulate that, with two-phase fluidization, the flow and density within the continuous phase are independent of the superficial gas velocity. Thus, for a given system, the Reynolds number in the continuous phase may be considered constant. The extension of the concept of a constant Reynolds number to include a range of particle sizes needs further verification.

Acknowledgment

The authors wish to express their appreciation to the Pittsburgh Consolidation Coal Co. for the fellowship under which this work was accomplished.

Notation

A = column area, sq.ft.

D_p = particle diameter, ft.

f = friction factor

g_c = conversion factor, 32.17 (ft.lb. mass)/(lb. force) (sec.)(sec.)

G = mass velocity; subscript $_{mf}$ refers to incipient fluidization; $_c$ refers to continuous phase when discontinuous phase is present, (lb.)/(hr.)(sq.ft.)

K, K', k', k = constants

L_f = bed height; subscript $_{mf}$ refers to height at incipient fluidization, ft.

ΔP = total pressure drop; subscript $_{ke}$ refers to kinetic energy loss; refers to incipient fluidization, lb./sq.ft.

t_k = time of detention of discontinuous phase within bed, sec.

u = velocity; subscript $_f$ refers to the superficial gas velocity based on total column cross

section; $_{mf}$ refers to the minimum superficial gas velocity necessary for fluidization; $_c$ refers to the superficial gas velocity in the continuous phase when the discontinuous phase is present; $_t$ refers to the terminal velocity or effective velocity which maintains the solid particles in suspension; $_p$ refers to the particle velocity with respect to the wall, ft./sec.

u_r = average gas velocity gradient with respect to the particle at the particle surface, sec.$^{-1}$

V = volume of gas per unit time; $_g$ refers to the flow rate in the discontinuous phase; $_c$ refers to the flow rate in the continuous phase, cu.ft./sec.

V_b = volume of the discontinuous phase in the system at any time, cu.ft.

W = work, ft.lb.

ϵ = fraction void space in continuous phase

μ = viscosity of gas; subscript $_g$ refers to true gas viscosity; $_e$ refers to the effective viscosity in a fluidized bed, (lb.)/(ft.)(sec.)

ρ = density; subscript $_g$ refers to gas; $_m$ refers to continuous phase; $_s$ refers to solid particles, lb./cu.ft.

Literature Cited

1. Bingham, E. C., "Fluidity and Plasticity," p. 199-201, McGraw-Hill Book Co., New York (1922).
2. Blake, F. C., *Trans. Am. Inst. Chem. Engrs.*, **14**, 415 (1922).
3. Bowman, J. R., "Mechanics of the Fluidized State," presented at the Annual Meeting *Am. Inst. Chem. Engrs.*, Pittsburgh, Pa. (Dec. 4-7, 1949).
4. Carman, P. C., *Trans. Inst. Chem. Engrs.* (London), **15**, 150 (1937).
5. Chilton, T. H., and Colburn, A. C., *Trans. Am. Inst. Chem. Engrs.*, **26**, 178 (1931).
6. Ergun, S., and Orning, A. A., *Ind. Eng. Chem.*, **41**, 1179 (1949).
7. Gamson, B. W., *Chem. Eng. Progress*, **47**, 19 (1951).
8. Hatschek, E., "An Introduction to the Physics and Chemistry of Colloids," fourth ed., p. 48-9, P. Blakiston's Son and Co., Philadelphia (1922).
9. Kettenring, K. N., Manderfield, E. L., and Smith, J. M., *Chem. Eng. Progress*, **46**, 139 (1950).
10. Leva, M., Grummer, M., Weintraub, M., and Pollchik, M., *Chem. Eng. Progress*, **44**, 511 (1948).
11. Leva, M., Grummer, M., Weintraub, M., and Pollchik, M., *Chem. Eng. Progress*, **44**, 619 (1948).
12. Lewis, W. K., Gilliland, E. R., and Bauer, W. C., *Ind. Eng. Chem.*, **41**, 1104 (1949).
13. Matheson, G. L., Herbst, W. A., and Holt, P. H., *Ind. Eng. Chem.*, **41**, 1099 (1949).
14. Mickley, H. S., and Trilling, C. A., *Ind. Eng. Chem.*, **41**, 1135 (1949).
15. Morse, R. D., *Ind. Eng. Chem.*, **41**, 1117 (1949).
16. Rouse, H., "Fluid Mechanics for Hydraulic Engineers, first ed., p. 210-13, McGraw-Hill Book Co., New York (1938).
17. Wilhelm, R. H., and Kwauk, M., *Chem. Eng. Progress*, **44**, 201 (1948).

Discussion

R. H. Wilhelm (Princeton (N. J.) University): The question has arisen as to whether the authors' treatment applies to systems which have a small amount of bubble formation. Particularly we were thinking about fluidization of solid particles with water as contrasted with the air-solid type of fluidization.

R. D. Toomey: We did not do any work with particulate fluidization such as that usually characterized by the fluidization of particles by water in which there is no apparent discontinuous phase. However, the data on particulate fluidization seem to be consistent with the concepts presented here. In examining the data of Wilhelm and Kwauk for particulate fluidization with water, the following observation can be made. When the fluid velocity was doubled to the highest values measured in the 13 runs reported, the average pressure drop increased about one per cent. In some cases there is actually a slight drop in pressure. In the same particle diameter range with air the pressure drop would increase on the order of 25% or more with any 100% increase in the fluid velocity. Therefore, it would seem that ΔP_{ke} as found in fluidization with a gas hardly exists with water fluidization where there is no discontinuous phase. The concepts presented in this paper predict this relationship, since the existence of ΔP_{ke} and the discontinuous phase are shown to be interdependent.

Max Leva (Pittsburgh, Pa.): Is it correct that your ΔP_{ke} constitutes an increase in pressure drop over values one would calculate from the weight of the bed?

R. D. Toomey: Yes. The pressure drop at the beginning of fluidization has been both calculated and measured and the results checked very closely.

Max Leva: According to that, the energy of fluidization which you report would be equal to the product of the volumetric flow rate of the gas and ΔP_{ke}. In this connection, what was your tube diameter and also how high was your bed?

R. D. Toomey: My tube diameter was 4.7 in. and the beds ranged from 12 in. to about 26 in.

Max Leva: We have had evidence in connection with our work at the U. S. Bureau of Mines that this pressure-drop increase ΔP_{ke} might be related to the height-diameter ratio of the bed. If one deals with shallow beds the increase is either entirely absent, or it is negligible even with gas fluidization. It has appeared that the increase might be primarily due to the friction of the solids on the wall. If that is so, it is difficult to see how the product of volumetric flow rate and ΔP_{ke} can be considered as being related to the energy of fluidization. At any rate it would be instructive to have particle velocities along the wall and compare them with heat-transfer data. Have you made such measurements and have you also observed temperature profiles?

R. D. Toomey: Yes, we took measurements on heat-transfer coefficients, temperature profiles, and particle velocities while obtaining the data presented in this paper. These relationships will be published later. I agree definitely with your previous paper in that the velocity of the particles along the wall appreciably affects the heat transfer.

I can't agree with the statement that the increased pressure drop might be due to the friction of the solids on the wall. It is true that the shallow beds have a low ΔP_{ke} and that this will increase with bed depth. This is probably due to the increase in the movement of particles which can be obtained with a deeper bed. The velocity of the particles is higher, causing the particles to have more of a spin and making them collide more often. Thus the bed depth is believed to affect the ΔP_{ke} through its effect on the particle movement throughout the fluidized system.

Max Leva: Have you compared your calculated values of the energy of fluidization with the product of total pressure drop, gas rate and fluidization efficiency? In the past our work at the U. S. Bureau of Mines has disclosed also a definite relationship between heat-transfer coefficients and the product just mentioned.

R. D. Toomey: No, we didn't make the comparison.

(Presented at Forty-third Annual Meeting, Columbus, Ohio.)

MASS-TRANSFER RATE IN PACKED COLUMNS

Its Analogy to Pressure Loss

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The coefficient of mass transfer, k_F, in fixed beds is shown to be a linear function of the fluid flow rate ρu:

$$k_F M_m = a'' + b''\rho u$$

where a'' and b'' are factors which are specific functions of fractional void volume, particle size, fluid viscosity and density, and coefficient of diffusion.

The analogy of mass-transfer rates to pressure loss in packed systems is expressed by the simple equation:

$$\frac{dC/dL}{\Delta C} = -\gamma \frac{dP/dL}{\rho\left(\frac{U}{\epsilon}\right)^2}$$

where γ is the proportionality factor which is shown to be $\frac{D_F\rho}{\mu}$. Based on this analogy, equations are developed which permit evaluation of mass-transfer rates independent of pressure drop.

A new general form of mass-transfer factor, applicable to all packed beds, is introduced. The existence of a one to one correspondence between the new mass-transfer factor and the new friction factor, introduced earlier for pressure drop in packed columns, is shown. Relationships developed are tested with the published data and their applicability demonstrated.

NUMEROUS industrial processes, such as coke or coal gasification, blast furnace operation, catalyst regeneration, adsorption, drying, solution, and many exchange processes involve interaction and mass and heat transfer between solid particles in fixed beds and the gas or liquid streams. The importance of evaluation of heat- and mass-transfer rates in such fixed beds to their design and successful operation is generally recognized and much discussed. However, the problem has been treated mostly on empirical bases and no correlation applicable to all types of systems has been found. The purpose of the present investigation has been (a) to review critically the existing methods of empirical correlations, (b) to point out their implications, (c) to review the theoretical developments, (d) to develop equations on theoretical grounds, and (e) to test the equations developed with the published data. The packed systems exhibit complexities, e.g., variations in temperature and pressure, changes in cross section, flow rates, solid surface areas, etc. Any general equation must necessarily be a differential one so as to permit integration over ranges of variables encountered. Available data on the subject, however meager, are fortunately for simple cases of constant temperatures and substantially constant flow rates. Thus the validity of the equations developed can be tested in a simple manner.

In the existing method of analysis, the mass-transfer coefficient, k_F, in packed beds is given by the following equation:

$$\frac{G}{M_m}(dC/dL) = k_F S_b (C^* - C) \qquad (1)$$

where G is the mass-flow rate of the fluid per unit cross-sectional area of the column, M_m is its molecular weight, C is the concentration of the solute in the main body of the fluid at a distance L from the entrance, C^* is the saturation concentration for the solute, and S_b is the surface area of the solids per unit volume of the bed. When integrated for the case of constant flow rate, isothermal flow, and no longitudinal mixing, Equation (1) takes the form:

$$k_F = \frac{G/M_m}{S_b L}\, ln \frac{C^* - C_1}{C^* - C_2} \qquad (2)$$

which is more frequently expressed as

$$k_F = \frac{G/M_m}{S_b L}\, \frac{C_2 - C_1}{\Delta C_{LM}} \qquad (3)$$

where

$$\Delta C_{LM} = \frac{C_2 - C_1}{ln \frac{C^* - C_1}{C^* - C_2}} \qquad (4)$$

A dimensionless parameter, the J_d factor, was introduced by Chilton and Colburn (*3*) for the purpose of relating the transfer coefficient k_F to the physical properties of the system:

$$J_d = \frac{k_F M_m}{G}\left(\frac{\mu}{\rho D_F}\right)^{2/3} \qquad (5)$$

where μ is the viscosity of the stream, ρ its density, and D_F the coefficient of diffusion of the solute into the solvent. For a better understanding of the implications of the J_d factor, k_F may be eliminated by the use of Equation (*2*).

$$J_d = \frac{D_p}{6L}\,\frac{1}{1-\epsilon}\left(\frac{\mu}{\rho D_F}\right)^{2/3} ln \frac{C^* - C_1}{C^* - C_2} \qquad (6)$$

where ϵ is the fractional void volume of the bed and D_p is the equivalent spherical diameter of the particles used in the packing. D_p is defined by

$$D_p = \frac{6(1-\epsilon)}{S_b} \qquad (7)$$

Chilton and Colburn (*3*) also introduced the concept of number of transfer units, N_t, defined by the expression

$$N_t = \int \frac{dC}{C^* - C}\,\frac{C_{BM}}{1 - C} \qquad (8)$$

where C_{BM} is the log mean solvent concentration in the column. For systems where solute concentrations are not large

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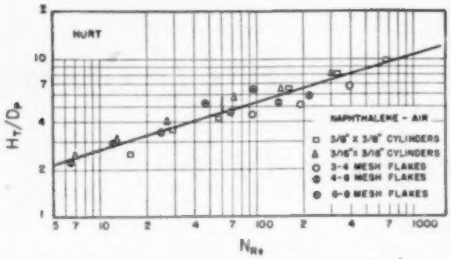


Fig. 1. Mass-transfer rates to gas streams in packed beds (12).

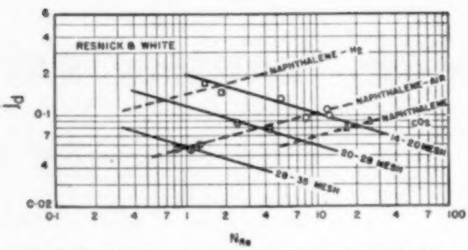


Fig. 2. Mass-transfer rates to gas streams in packed beds (18).

and no mixing occurs along the length of the bed, Equation (8) can be integrated as

$$N_t = \ln \frac{C^* - C_1}{C^* - C_2} \tag{9}$$

The height of a transfer unit, H_t, is obtained by dividing the column height L by the number of transfer units N_t,

$$H_t = \frac{L}{N_t} = \frac{L}{\ln \dfrac{C^* - C_1}{C^* - C_2}} \tag{10}$$

The factors defined above, viz., k_p, J_d, H_T, and N_t, can be calculated from the data taken from a column in operation. The problem lies in predicting any of these factors for another system to be designed, or for the same system under different flow conditions. The J_d factor, in particular, was introduced for this purpose. Unfortunately, however, the relations obtained by various workers differ in many respects and fail usually to agree with one another as will be seen from the following brief review.

Work of Gamson, Thodos and Hougen (*10*). Psychrometric measurements were made for studying the rate of evaporation of water from spherical and cylindrical porous pellets into air streams. The porous pellets were soaked in water, ". . . usually several hours, the excess water was drained off, the pellets were rolled in cheesecloth to remove the excess water adhering to the surface without removing capillary moisture." It is, therefore, expected that the interfacial surface area between the gas stream and the liquid was different from the geometric surface area of the solids on which the calculation of the transfer coefficients were based. Bed thicknesses not exceeding 2½ in. were used for particle sizes as large as ¾ in. In such shallow beds the entrance and exit effects may play important roles. Moreover, the height and the fractional void volume for a bed made up of a few layers of solids are quantities of questionable significance. The data were presented by plotting the J_d factor against the Reynolds number, $N_{Re} = GD_p/\mu$. The following equations were recommended:

$$J_d = 0.989\left(\frac{D_pG}{\mu}\right)^{-0.41} \quad \text{for} \quad \frac{D_pG}{\mu} > 350 \tag{11a}$$

$$J_d = 16.8\left(\frac{D_pG}{\mu}\right)^{-1} \quad \text{for} \quad \frac{D_pG}{\mu} < 40 \tag{11b}$$

Work of Wilke and Hougen (*22*). Additional data to that of Gamson, Thodos and Hougen (*10*) were obtained for the purpose of investigating further the region of lower gas flow rate. Equation (11*b*) was replaced with

$$J_d = 1.82\left(\frac{D_pG}{\mu}\right)^{-0.51} \quad \text{for} \quad \frac{D_pG}{\mu} < 100 \tag{11c}$$

Work of Hurt (*12*). The following systems were studied: (a) the adsorption of water vapor from moist air by particles of silica gel and by particles coated with phosphorous pentoxide, (b) adiabatic humidification of air over silica gel pellets wetted with water, (c) evaporation of naphthalene from naphthalene flakes into air and hydrogen streams. The result for case (a) was considered doubtful. Data were given for cases (b) and (c) together with the results of H_T calculations. The fractional void volumes were not measured. It was reported that ". . . for different size particles of similar shape no satisfactory correlation of the data into a single curve could be obtained. Data are, accordingly, presented as separate curves for each size and shape investigated." The author apparently did not recognize that the plot of H_T/D_p against D_pG/μ would bring the data for different sizes into a single line as seen from Figure 1.

Work of Resnick and White (*18*). Rates at which naphthalene was vaporized into air, hydrogen, and carbon dioxide streams from fixed and fluidized beds were measured. The J_d factors were calculated and, when presented graphically against D_pG/μ, a wide scatter attributed to differences in size, was observed. Results are shown in Figure 2. A statistical analysis of the data indicates that no significant correlation exists between the reported J_d factors and the Reynolds numbers; in fact, the dotted lines shown in Figure 2 may represent the data equally well. The authors correlated their data empirically by plotting $J_d/D_p^{1.5}$ vs. D_pG/μ.

Work of Taecker and Hougen (*21*). Studies were identical with those of Gamson, Thodos and Hougen (*10*) and Wilke and Hougen (*22*), except that Raschig rings, partition rings, and Berl saddles were used instead of spheres and cylinders. The effective particle diameter, D_p', for the special shape packings used, was calculated by $D_p' = \sqrt{A_p/\pi}$, where A_p is the dry surface area for one packing unit. Even with this modification, the J_d factors for Raschig rings and partition rings were 19% lower than those for solid spheres and cylinders and for Berl saddles about 30% higher than for the rings. To express the data the following equations were developed:

$$J_d = 1.251\left(\frac{GD_p'}{\mu}\right)^{-0.41} \quad \text{for} \quad \frac{GD_p'}{\mu} > 620 \tag{11d}$$

$$J_d = 2.24\left(\frac{GD_p'}{\mu}\right)^{-0.51} \quad \text{for} \quad \frac{GD_p'}{\mu} < 620 \tag{11e}$$

Work of Hobson and Thodos (*11*). Water was passed through a bed of celite spheres presoaked in a saturated solution of either water in isobutyl alcohol or of water

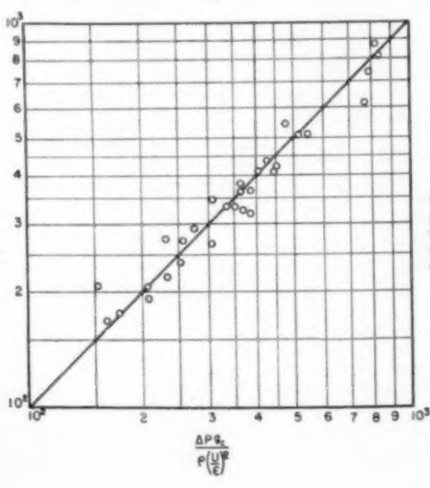


Fig. 3. Analogy between pressure drop and mass-transfer rate into liquid streams in packed beds on 2-naphthol-water system (15).

in methyl ethyl ketone. The variation of the effluent concentration with time was measured so that the transfer rates would be calculated at "zero time" when the particles were believed to be completely wetted by saturated solution. The questions that concerned later workers (8) were: (1) how accurate was the extrapolation to a somewhat uncertain "zero time" for a curve of rapidly changing slope? (2) did the pellets have excess solution on their surface initially? (3) if not, how was this removed without depleting the surface? The following generalized equation, correlating also the data of Gamson, et al. (10), and Wilke and Hougen (22), was recommended by the authors:

$$\log J_d = 0.7683 - 0.9175 \log Re + 0.0817[\log Re]^2 \qquad (11f)$$

Work of McCune and Wilhelm (15). Mass-transfer rates from 2-naphthol pellets into water streams were measured. The work of these authors constituted an excellent investigation free from most of the uncertainties of the earlier studies. Use of uniform size pellets assured accurate estimation of the geometric surface area of the solids which constituted both the surface exposed to flow and the interfacial surface for mass transfer. Ample bed heights were used. The fractional void volumes of the fixed beds could have been easily calculated from the bulk densities, ρ_B, and the particle density of the pellets, ρ_S, by the use of the relationship $\epsilon = 1 - \rho_B/\rho_S$. This, however, apparently was overlooked by the authors, who determined the fractional void volume for each type of packing in a separate apparatus, although the pellets may not have packed to the same bulk densities in the separate container. Data were presented as a plot of the J_d factor against Reynolds number, and data were represented by two straight lines:

$$J_d = 1.625\left(\frac{D_pG}{\mu}\right)^{-0.507} \text{ for } \frac{D_pG}{\mu} < 120 \qquad (11g)$$

$$J_d = 0.687\left(\frac{D_pG}{\mu}\right)^{-0.327} \text{ for } \frac{D_pG}{\mu} > 120 \qquad (11h)$$

Work of Gaffney and Drew (8). Studies of these authors comprise a thorough investigation of mass-transfer rates in solid-liquid systems. The work was similar in nature to that of McCune and Wilhelm (15). The actual fractional void volumes of the beds were determined for each case. The following systems were investigated: (a) benzene-salicylic acid, (b) *n*-butanol-succinic acid and (c) acetone-succinic acid. The preferred method of presenting the data consisted of plotting $S_bH_T/Sc^{0.58}$ against $D_pG/\mu\epsilon$, which also correlated the data of McCune and Wilhelm (15). The reciprocal of the former of these groups is identical with the J_d factor used by the earlier workers, except that the Schmidt number, $Sc = \mu/\rho D_v$, entered with 0.58 power instead of the customary 2/3 power. The reciprocal of the plot of the authors could approximately be expressed by the following equations:

$$J_d' = 1.97\left(\frac{D_pG}{\mu\epsilon}\right)^{-0.[illegible]} \text{ for } \frac{D_pG}{\mu\epsilon} < 200 \qquad (11i)$$

$$J_d' = 0.290\left(\frac{D_pG}{\mu\epsilon}\right)^{-0.[illegible]} \text{ for } \frac{D_pG}{\mu\epsilon} > 200 \qquad (11j)$$

where

$$J_d' = \frac{Sc^{0.58}}{S_bH_T} = \frac{k_yM_m}{G}\left(\frac{\mu}{\rho D_v}\right)^{0.58}$$

TABLE 1.—EMPIRICAL EQUATIONS FOR THE J_d FACTORS*

Equations
$J_d = 16.8\left(\frac{D_pG}{\mu}\right)^{-1}$ for $\frac{D_pG}{\mu} < 40$ (10)
$J_d = 0.989\left(\frac{D_pG}{\mu}\right)^{-0.41}$ for $\frac{D_pG}{\mu} > 350$ (10)
$J_d = 1.82\left(\frac{D_pG}{\mu}\right)^{-0.51}$ for $\frac{D_pG}{\mu} < 100$ (22)
$\frac{{}^{\circ}J_d}{D_p^{1.5}} = 0.19\left(\frac{D_pG}{\mu}\right)^{-0.[illegible]}$ for $\frac{D_p'G}{\mu} < 25$ (18)
$^{**}J_d = 2.24\left(\frac{D_p'G}{\mu}\right)^{-0.51}$ for $\frac{D_p'G}{\mu} < 620$ (21)
$J_d = 1.251\left(\frac{D_p'G}{\mu}\right)^{-0.41}$ for $\frac{D_p'G}{\mu} > 620$ (21)
$J_d = 1.625\left(\frac{D_pG}{\mu}\right)^{-0.507}$ for $\frac{D_pG}{\mu} < 120$ (15)
$J_d = 0.687\left(\frac{D_pG}{\mu}\right)^{-0.327}$ for $\frac{D_pG}{\mu} > 120$ (15)
$^{***}J_d' = 1.97\left(\frac{D_pG}{\mu\epsilon}\right)^{-0.[illegible]}$ for $\frac{D_pG}{\mu\epsilon} < 200$ (8)
$J_d = 0.290\left(\frac{D_pG}{\mu\epsilon}\right)^{-0.[illegible]}$ for $\frac{D_pG}{\mu\epsilon} > 200$ (8)
$\log J_d = 0.7683 - 0.9175 \log \frac{D_pG}{\mu} + 0.0817\left(\log \frac{D_pG}{\mu}\right)^2$ (11)

*J_d is defined by Equation (5).
°D_p is in mm.
**D_p' is defined as $\sqrt{A_p/\pi}$ where A_p is dry surface area for one packing unit.
***J_d' is defined following Equation (11j).

The working equations proposed by the authors mentioned above are tabulated in Table 1 for purposes of comparison. The lack of agreement shown in these correlations indicates the necessity of an analysis of the problem based on more fundamental considerations before relationships valid for all systems can be derived.

The factors determining the rates of mass transfer in packed beds are numerous and some of them are not susceptible to exact mathematical treatment. There is available, however, the Reynolds analogy between heat transfer and resistance offered to fluid flow by friction, and Colburn's extension (4, 5) of this analogy to mass-transfer rates which permit the development of theoretical expressions for heat- and mass-transfer rates. For a better understanding of the analogy, the theoretical developments will be briefly reviewed.

Osborne Reynolds (19) deduced from the molecular theory of fluids the laws for the transmission of heat and for the resistance offered by friction to the motion of the fluids. He stated that the rate of heat transmission depends on: "(1) . . . the thermal internal diffusion of the fluid when at rest and (2) the eddies caused by visible motion which mixes the fluid up and continually brings fresh particles into contact with the surface.

"The first of these causes is independent of the velocity of the fluid and, if it be a gas, is independent of its density, so that it may be said to depend only on the nature of the fluid.

"The second cause, the effect of eddies, arises entirely from the motion of the fluid and is proportional to the density of the fluid, if gas, and the velocity with which it flows past the surface."

The combined effect of these two causes was expressed in his formula:

$$H = a'\Delta t + b'\rho u\Delta t \qquad (12)$$

where a' and b' are constants depending upon the nature of the fluid, $\Delta t = t^* - t$, the difference in temperature between the surface and the fluid, ρ the density of the fluid, u its velocity and H the heat transmitted per unit area of the surface in a unit of time.

The resistance offered by friction to the motion of fluid was expressed by Reynolds in the formula:

$$R = au + b\rho u^2 \qquad (13)$$

Reynolds further stated that ". . . various considerations lead to the supposition that a' and b' in (12) are proportional to a and b in (13)."

Based on the same theory, mass-transfer rate also depends on the natural internal diffusion when at rest and on the eddies caused by the visible motion of the fluid which mixes the fluid and continually brings fresh particles into contact with the surface. Expressed in a formula:

$$w = a''\Delta C + b''\rho u\Delta C \qquad (14)$$

where $\Delta C = C^* - C$, the difference in concentration of the diffusing substance between the surface and the fluid, and w is the mass transmitted per unit area of the surface of transfer in a unit of time. In this case also a'' and b'' might be expected to be proportional to a and b.

For fluid flow in a circular pipe of diameter D whose walls constitute the surface of transfer, the quantities H, R and w for a differential length dL of the tube can be expressed as:

$$H = \frac{\rho u(\pi D^2/4)cdt}{\pi DdL} = \rho uc\frac{D}{4}\frac{dt}{dL} \qquad (15a)$$

$$R = -\frac{(\pi D^2/4)dP}{\pi DdL} = -\frac{D}{4}\frac{dP}{dL} \qquad (15b)$$

$$w = \frac{\rho u(\pi D^2/4)dC}{\pi DdL} = \rho u\frac{D}{4}\frac{dC}{dL} \qquad (15c)$$

If a' and b' are proportional to a and b as Reynolds supposed, dividing Equation (13) by (12) and substituting Equations (15a) and (15b) properly, will yield

$$\frac{dt/dL}{\Delta t} = -\lambda\frac{dP/dL}{\rho u^2} \qquad (16)$$

where λ represents the proportionality constant and includes the heat capacity of the fluid c, so that λ is dimensionless, i.e.,

$$\lambda = \frac{1}{c}\frac{a'}{a} = \frac{1}{c}\frac{b'}{b}$$

Similarly, for mass transfer and pressure loss, from Equations (13), (14), (15b), and (15c):

$$\frac{dC/dL}{\Delta C} = -\gamma\frac{dP/dL}{\rho u^2} \qquad (17)$$

where γ represents the constant of proportionality of a and b with a'' and b'', i.e.,

$$\gamma = \frac{a''}{a} = \frac{b''}{b}$$

To express the Reynolds analogy in words Chilton and Colburn (3) and Sherwood (20) postulated: "The ratio of the

momentum lost by skin friction between two sections a differential distance apart to the total momentum of the fluid will be the same as the ratio of the heat actually supplied by the surface to that which would have been supplied if the whole of the fluid had been carried up to the surface." This interpretation is erroneous in that it leads to an equality between $dP/\rho u^2$ and $dt/\Delta t$, which disagrees with the statement of Reynolds which specifically indicates a proportionality between a' and b' of Equation (12) and a and b of Equation (13), and leads to the proportionality expressed in Equation (16).

This misinterpretation of Reynolds' argument has apparently been generally accepted even though Nusselt (*16*) had earlier demonstrated the analogy between heat transfer and pressure drop and found that the heat-transfer coefficient $h(=H/\Delta t)$ from the walls of a pipe to a gas flowing through the pipe was approximately proportional to the 0.786 power of the gas velocity, and under identical conditions the pressure loss was proportional to the 1.776 power of the velocity. This observation led Nusselt to postulate that the difference in exponents should be unity, thereby leading to the expression:

$$\frac{H}{\Delta t} \propto \frac{R}{u} \tag{18a}$$

which is in conformity with the Reynolds supposition. Nusselt chose to correlate the heat-transfer coefficients in terms of the two dimensionless groups: $Du\rho/\mu$ and $c\mu/k$ where k is the thermal conductivity of the fluid.

$$h = \frac{k}{D}\phi\left(\frac{Du\rho}{\mu}, \frac{c\mu}{k}\right) = \frac{k}{D}\left(\frac{c\mu}{k}\right)^{n}\left(\frac{Du\rho}{\mu}\right)^{n'} \tag{18b}$$

His experimental results indicated that the pressure drop could be expressed as:

$$-\frac{dP}{dL} = \frac{u\mu}{D^2}\psi\left(\frac{Du\rho}{\mu}\right) = \frac{u\mu}{D^2}\left(\frac{Du\rho}{\mu}\right)^{n''} \tag{18c}$$

The observed values were: $n = 0.85$, $n' = 0.786$, and $n'' = 0.776$. It was believed that $n' \approx n''$, therefore a comparison between Equations (18*b*) and (18*c*) indicated that the proportionality constant of Equation (18*a*), i.e., the analogy between heat transfer and pressure loss, is $(k/c\mu)^n$ which is identical to what is known as the Chilton and Colburn analogy for heat transfer (*3*). Nusselt further believed that $n' \approx n$ which enabled the combination of two dimensionless groups leading to the expression

$$h = \frac{k}{D}\left(\frac{Du\rho c}{k}\right)^{0.786} \tag{18d}$$

The investigation of the later workers (*14*) did not indicate an equality between n' and n. Equation (18*b*), however, is widely used (*14*).

Prandtl (*17*) made a theoretical analysis of heat transfer and pressure drop in pipes and observed that the analogy arrived at by Nusselt is only possible if the conductivity of the fluid is equal to the product of its specific heat and its absolute viscosity, i.e., $k = c\mu$, which is approximately true for gases. According to Prandtl, if $k \neq c\mu$, a mathematical solution to the problem is possible by making the following assumptions: (1) there exists a laminar fluid layer near the wall through which heat is carried by conduction alone, and (2) the remainder of the fluid body is the turbulent core where convection causes the heat transfer. His theoretical development led to the following equation:

$$h = \frac{\frac{D}{4}c}{\left[1-\left(1-\frac{c\mu}{k}\right)\frac{u_B}{u}\right]}\frac{1}{u}\frac{dP}{dL} \tag{18e}$$

If Equation (15*a*) is substituted into (18*e*) and H is replaced by $h\Delta t$,

$$\frac{dt/dL}{\Delta t} = -\frac{1}{\left[1-\left(1-\frac{c\mu}{k}\right)\frac{u_B}{u}\right]}\frac{dP/dL}{\rho u^2} \tag{19}$$

where u_B is the fluid velocity at the boundary between the eddy core and laminar layer, and u the average velocity of the main fluid stream. A similar transformation of the Nusselt equation (18*a*) gives:

$$\frac{dt/dL}{\Delta t} = -\left(\frac{k}{c\mu}\right)^{n}\frac{dP/dL}{\rho u^2} \tag{20}$$

A comparison of Equations (19) and (20) with Equation (16) indicates that the proportionality constant λ of the Reynolds theory is $(k/c\mu)^n$ according to Nusselt and

$$\frac{1}{\left[1-\left(1-\frac{c\mu}{k}\right)\frac{u_B}{u}\right]}$$

according to Prandtl. None of these advancements is contrary to the Reynolds supposition.

Extension of the Reynolds analogy to mass transfer is due to Colburn (*4, 5*) and Chilton and Colburn (*3*). Colburn treated the problem of interphase material transfer through a gas in turbulent motion in a manner similar to that of Prandtl. The Colburn equation, when expressed for a differential length dL, is given by:

$$\frac{dC/dL}{\Delta C} = -\frac{1}{\left[1-\left(1-\frac{\mu}{\rho D_V}\right)\frac{u_B}{u}\right]}\frac{dP/dL}{\rho u^2} \tag{21}$$

The Chilton and Colburn equation of mass transfer is analogous to the Nusselt equation for heat transfer:

$$\frac{dC/dL}{\Delta C} = -\left(\frac{\rho D_V}{\mu}\right)^{n}\frac{dP/dL}{\rho u^2} \tag{22}$$

where n was reported to be 2/3. From a comparison of Equations (21) and (22) with Equation (17), it is seen that the proportionality factor γ is $(\rho D_V/\mu)^{2/3}$ according to Chilton and Colburn and

$$\frac{1}{\left[1-\left(1-\frac{\mu}{\rho D_V}\right)\frac{u_B}{u}\right]}$$

according to Colburn.

The application of the analogy expressed in Equation (17) to the data obtained for the gas flow inside tubes has been fairly successful. Its application to a packed column, a case widely encountered in practice, has not been demonstrated. Indeed, the possibility of an existence of a correlation between pressure drop and mass-transfer rate in packed columns has been questioned by Gamson, Thodos and Hougen (*10*). It has been shown (*6, 7*), however, that the pressure loss through a packed bed follows Equation (13) set forth by Reynolds, and the constants a and b were found to be specific functions of fractional void volume and height of the bed, particle size, and fluid viscosity. It should be possible, therefore, to obtain theoretical equations formally relating heat- and mass-transfer rates to pressure drop in packed columns. The simplest method of establishing an analogy would be to investigate the proportionality expressed in Equation (17) and the nature of the factor γ.

For the sake of convenience it has been the custom to use the superficial fluid velocity U, based on the empty column, instead of the actual fluid velocity u; since $u = U/\epsilon$, where ϵ is the fractional void volume, its substitution into Equation (17) leads to

$$\frac{dC/dL}{\Delta C} = -\gamma\epsilon^2\frac{dP/dL}{\rho U^2} \tag{23}$$

To integrate Equation (23), it is necessary to know the variation of ΔC with L. There are two extreme cases which permit direct integration: (1) the fluid is completely mixed in the bed and (2) the fluid is not mixed. For the case of complete mixing, ΔC is constant and equal to $C^* - C_2$ where the subscript 2 refers to the exit concentration. Integration of Equation (23) then leads to:

$$\frac{C_2 - C_1}{C^* - C_2} = \gamma\epsilon^2\frac{\Delta P}{\rho_m U_m^2} \tag{24a}$$

where the subscript 1 refers to the condition at the entrance, and m at the average pressure. If there is no mixing along the length of the column, then

$$\ln\frac{C^* - C_1}{C^* - C_2} = \gamma\epsilon^2\frac{\Delta P}{\rho_m U_m^2} \tag{24b}$$

Usually $(C_2 - C_1)/\Delta C_{LM}$ is used instead of $\ln(C^* - C_1)/(C^* - C_2)$ which is in accord with the definition of ΔC_{LM} expressed in Equation (4). For the case of complete mixing, the plot of the left-hand side of Equation (24*a*) against $\epsilon^2\Delta P/\rho_m U_m^2$ should give a straight line passing through the origin. The slope of the line is the proportionality factor γ. For the case of no longitudinal mixing the same is true for Equation (24*b*). Thus, such plots offer a means to ascertain which one of the cases a given system approximates and, at the same time, to investigate the proportionality factor. A study of the data of McCune and Wilhelm (*15*) indicated that their system approximated the case of no mixing of the fluid along the length of the column since a graphical representation of Equation (24*b*) rather than (24*a*) yielded a straight line. The slope γ also was equal to $\rho D_V/\mu$ as required by theory. Unfortunately, however, most workers have not reported the pressure

drop with the mass-transfer data, and in the absence of any additional data which include pressure drop, it was necessary to calculate the expected pressure drop from the general pressure-drop equation presented earlier (*7*):

$$\frac{\Delta P}{\rho_m U_m^2} = 150\frac{(1-\epsilon)^2}{\epsilon^3}\frac{\mu L}{G D_p^2} + 1.75\frac{1-\epsilon}{\epsilon^3}\frac{L}{D_p} \qquad (25)$$

Studies of the data of Gaffney and Drew (*8*) and Hobson and Thodos (*11*) indicated no mixing and that the proportionality factor γ is $\rho D_F/\mu$. The substitution of $\rho D_F/\mu$ in place of γ in Equations (24*a*) and (24*b*) results in

$$\frac{\mu}{\rho D_F}\frac{C_2 - C_1}{C^* - C_2} = \epsilon^2\frac{\Delta P}{\rho_m U_m^2} \qquad (26a)$$

and

$$\frac{\mu}{\rho D_F}\, ln\frac{C^* - C_1}{C^* - C_2} = \epsilon^2\frac{\Delta P}{\rho_m U_m^2} \qquad (26b)$$

for cases of complete mixing and no mixing, respectively. The evaluation of mass-transfer rates independent of pressure drop requires that the pressure drop be eliminated from Equations (26*a*) and (26*b*) by the use of Equation (25) resulting in:

$$\frac{D_p}{L}\frac{\epsilon}{1-\epsilon}\frac{\mu}{\rho D_F}\frac{C_2 - C_1}{C^* - C_2} = 150\frac{\mu(1-\epsilon)}{D_p G} + 1.75 \qquad (27a)$$

for the case of complete mixing, and

$$\frac{D_p}{L}\frac{\epsilon}{1-\epsilon}\frac{\mu}{\rho D_F}\, ln\frac{C^* - C_1}{C^* - C_2} = 150\frac{\mu(1-\epsilon)}{D_p G} + 1.75 \qquad (27b)$$

for the case of no mixing. The forms of Equations (27*a*) and (27*b*) are similar to that of the friction factor introduced in an earlier paper (*7*):

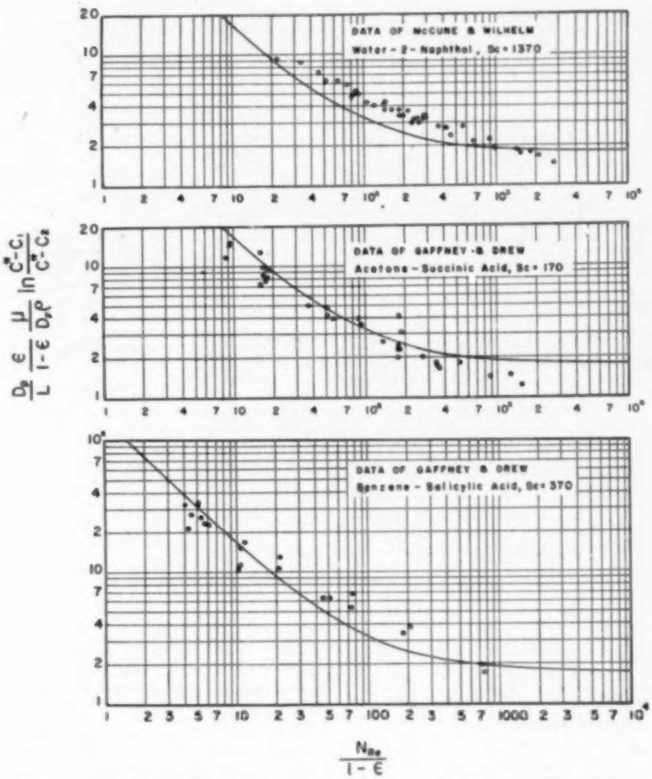
$$f_k = \frac{D_p}{L}\frac{\epsilon^3}{1-\epsilon}\frac{\Delta P}{\rho_m U_m^2} = 150\frac{\mu(1-\epsilon)}{D_p G} + 1.75 \qquad (28)$$

The unintegrated forms of the left-hand sides of Equations (27*a*) and (27*b*) are the same, and if represented by J,‡ then

$$J = \frac{D_p}{L}\frac{\epsilon}{1-\epsilon}\frac{\mu}{\rho D_F}\int\frac{dC}{\Delta C} = 150\frac{\mu(1-\epsilon)}{D_p G} + 1.75 \qquad (29)$$

From Equations (28) and (29) it is seen that

‡ New symbol.



Figs. 4 (above), 5 (middle) and 6 (below). Mass-transfer rates into liquid streams in packed beds. Solid lines are the plot of $\left[150\frac{(1-\epsilon)}{N_{Re}} + 1.75\right]$ vs. $\frac{N_{Re}}{(1-\epsilon)}$.

$$J = f_k \qquad (30)$$

Data of McCune and Wilhelm are presented graphically in Figure 3 by plotting

$$\frac{\mu}{\rho D_F}\, ln\frac{C^* - C_1}{C^* - C_2} \text{ vs. } \epsilon^2\frac{\Delta P}{\rho_m U_m^2}$$

according to Equation (26*b*). It is seen that there exists a one-to-one correspondence between the coordinates. Since the data of the other workers discussed in earlier paragraphs did not include pressure drop, a similar representation of their data is not possible. They are, however, plotted in Figures 4-8 according to Equation (27*b*). In these figures the points are the plot of the left-hand side of Equation (27*b*) vs. $D_pG/\mu(1-\epsilon)$ and the solid lines

$$\left[150\frac{\mu(1-\epsilon)}{D_p G} + 1.75\right] \text{ vs. } \frac{D_p G}{\mu(1-\epsilon)}$$

The points represent the experimental data and the line the analogy. Thus the applicability of the analogy to the experimental data is tested. Figure 9 shows a plot of data for pressure drop in packed beds. In Figure 10 the data presented in Figures 4, 6 and 8 are grouped * for the purpose of comparison with Figure 9. In both figures the solid lines are identical with those in Figures 4-8. A close study and comparison of Figures 9 and 10 indicate that a simple and theoretical analogy exists between pressure drop and mass-transfer rate into liquid streams in packed columns.

Application of the analogy just shown for the liquid streams to the reported data for gas streams in packed columns has not been successful largely because of the deficiency and uncertainty of the data. Analyses of the data based on the assumption that no longitudinal mixing occurs indicate that the proportionality factor γ is of the order of magnitude

* Data of Figure 7 are excluded in 9 because of their wide deviation which may be attributed to influence of free convection, circulation, streaming and header effects discussed by authors. For *n*-butanol-succinic acid system, the influence of these factors and other disturbances are no longer negligible.

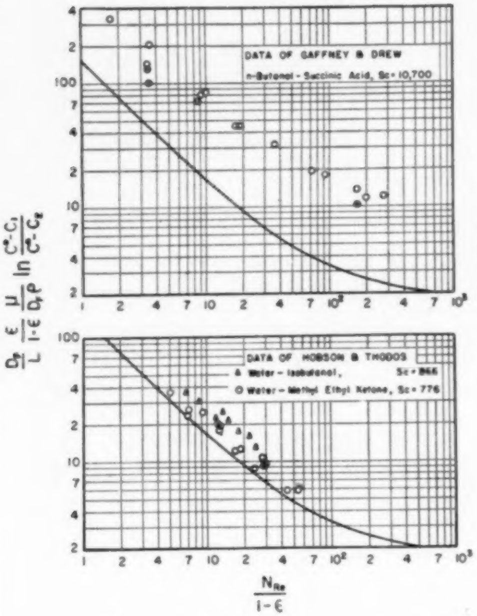


Fig. 7 (above) and Fig. 8 (below). Mass-transfer rates into liquid streams in packed beds. Solid lines are the plot of

$$\left[150\,\frac{(1-\epsilon)}{N_{Re}}+1.75\right] \text{ vs. } \frac{N_{Re}}{(1-\epsilon)}.$$

$$\frac{1}{10}\,\frac{\rho D_F}{\mu} \text{ to } \frac{1}{50}\,\frac{\rho D_F}{\mu}$$

The exponent n of the Chilton and Colburn factor would be negative for

$$\frac{\mu}{\rho D_F} < 1$$

and positive for

$$\frac{\mu}{\rho D_F} > 1$$

if the mass-transfer data reported are to be compared with the reported or expected pressure drop (Equation (*24b*)). Moreover, the absolute value of n would be much larger than unity. In order to apply the Colburn factor to bring about a comparison, for all positive values of u_B/u it is necessary that $\mu/\rho D_F$ be greater than unity. For the naphthalene air system of Hurt, for example, $\mu/\rho D_F$ is reported to be 1.84 and based on this figure the value calculated for u_B/u exceeds 40. Data of Gamson, Thodos and Hougen (*10*), Wilke and Hougen (*22*), Hurt (*12*), and Resnick and White (*18*) are shown in Figure 11. The line above is the plot of

$$\left[150\,\frac{\mu(1-\epsilon)}{D_pG}+1.75\right] \text{ vs. } \frac{D_pG}{\mu(1-\epsilon)}$$

and the lines below are the plots* of the left-hand side of Equation (*27b*) vs. $D_pG/\mu(1-\epsilon)$.

* For gases, partial pressure p is used in place of concentration C.

These lines were either obtained from separate plots by drawing best lines or were calculated from the equations given by the authors. Sections of the lines calculated from the equations are dotted if not covered by the original data. Wherever the fractional void volumes were not reported, a value 0.4 was used for ϵ to make the graphical representation possible.

Before attempting to draw an adverse conclusion for the inclusion of the gas streams in the analogy, the deficiency of the data reported for the gas phase must be considered. Data of Gamson, Thodos and Hougen and those of Wilke and Hougen are too uncertain with respect to the surface area available for mass transfer, the bed height and the fractional void volume. Data of Resnick and White are inconsistent and show no significant correlation on any theoretical ground. Although the data of Hurt do not include pressure loss nor the fractional void volume, they show consistency and permit analysis. The first analysis made was for the purpose of determining which one of the cases the system approximated, i.e., no mixing or complete mixing. According to Equation (*27a*), for a system with complete mixing the plot of

$$\frac{C_2-C_1}{C^*-C_2} \text{ vs. } \frac{1}{G}$$

should yield a straight line with a positive slope and intercept (every other factor being fixed for a system at constant temperature and pressure). For systems where no longitudinal mixing occurs, the plot of

$$\ln\frac{C^*-C_1}{C^*-C_2} \text{ vs. } \frac{1}{G}$$

should yield a straight line according to Equation (*27b*). For systems where partial mixing occurs, a plot of

$$\frac{C_2-C_1}{\Delta C} \text{ vs. } \frac{1}{G}$$

should result in a straight line if ΔC's are chosen properly. Values of ΔC should lie between C^*-C_2 and ΔC_{LM} which are the limiting conditions, i.e., $C^*-C_2<\Delta C<\Delta C_{LM}$. For the naphthalene-air system of Hurt, plots of

$$\frac{p_2-p_1}{p^*-p_2} \text{ vs. } \frac{1}{G}$$

yielded straight lines whereas plots of

$$\ln\frac{p^*-p_1}{p^*-p_2} \text{ vs. } \frac{1}{G}$$

definitely exhibited curved shapes as seen from Figures 12 and 13. The foregoing treatment establishes that the experiments of Hurt with gas streams involved complete mixing. Therefore, Equations (*26a*) or (*27a*) should be used. Also, on this basis, it can be concluded that the gas streams in shallow beds involve complete mixing. Consequently, the use of the J_d factor and H_T as defined respectively by Equations (5) and (10) is basically improper. These quantities imply piston flow which is not always true for gas streams.

Data of Hurt are presented in Figure 14 according to Equation (*27a*). The points represent the experimental data and the line is identical with those in Figures 4-10. The experimental points fall below the line by a factor in the neighborhood of 5. It is not the present intent to blame the experimental data for the deviation. Data of Hurt are gratifying for the opportunity they permit for understanding the mechanism of mass transfer into gas streams. The following points, however, do not fail to attract attention:

1. The reported value of $\mu/\rho D_F$ by Hurt for the diffusion of naphthalene into air is 1.84, whereas for the same system a value of 2.39 is given by Resnick and White.
2. The recorded values for the vapor pressure of naphthalene are higher than those calculated from the International Critical Tables (*13*) which in turn are different from those reported by Resnick and White. The differences are not insignificant; in fact, a different set of vapor pressure data will bring the experimental points of Figure 14 above the solid line.

It may seem futile to arrive at definite conclusions for the extension of the analogy to gas streams until consistent data are available which include information about pertinent variables. Liquid

and gas streams, however, should be treated alike and the variables concerned should be evaluated on comparable bases. This is especially true for calculation of the Schmidt number. As pointed out by Gaffney and Drew, the diffusivities reported may not have been calculated on the same basis for liquids and gases.

In the treatment thus far, the mass-transfer factor J has been given principal consideration. The treatment also makes possible the development of a theoretical expression for the mass-transfer coefficient, k_F, analogous to heat-transfer coefficient, h: by definition

$$k_F M_m = \frac{w}{\Delta C} \qquad (31)$$

From Equations (14) and (31):

$$k_F M_m = a'' + b'' \rho u \qquad (32)$$

Evaluation of the constants a'' and b'' from their relation to a and b of Equation (13) and from Equation (25) gives the following:

$$a'' = \frac{150}{6} \frac{1-\epsilon}{\epsilon} \frac{\mu}{D_p} \frac{D_F \rho}{\mu} \qquad (33)$$

$$b'' = \frac{1.75}{6} \frac{D_F \rho}{\mu} \qquad (34)$$

From Equations (32)-(34) it is evident that the mass-transfer coefficient k_F is linear with respect to mass flow rate. In Figure 15 this is demonstrated by use of the data of Wilke and Hougen (*22*). Since in this data D_p and ϵ were varied, it was necessary to include them in the coordinates in order to eliminate the effect of their variation as required by the above equations.

The justifications for introducing the new general definition of the mass-transfer factor proposed in this paper, aside from the ease it permits in estimating the transfer rates, are: (1) it makes possible a general representation of data and (2) it demonstrates an analogy to pressure drop and heat transfer. The transformation of the J_d factor which is shown in Equation (6) and the new mass-transfer factor, J, represented by Equation (29) differ by

$$6\epsilon\left(\frac{\mu}{\rho D_F}\right)^{2/3}$$

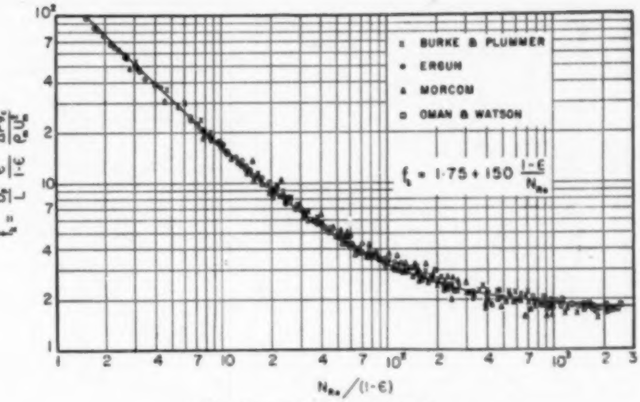


Fig. 9. Pressure drop in packed beds. Solid line is identical with those in Figs. 4-8.

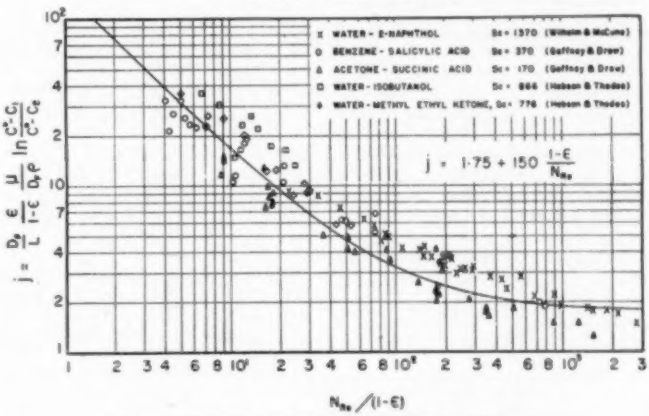


Fig. 10. Mass-transfer rates into liquid streams in packed beds. Solid line is identical with those in Figs. 4-8.

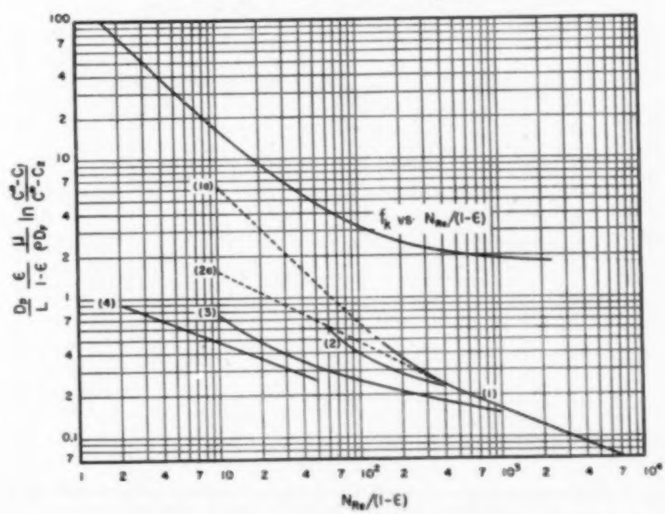
Fig. 11. Mass-transfer rates into gas streams in packed beds. ⟶

The line above is the plot of

$$\left[150\frac{(1-\epsilon)}{N_{Re}} + 1.75\right] \text{vs.} \frac{N_{Re}}{(1-\epsilon)}.$$

(1) Data (*10*)
(1a) Extrapolation of (*1*) according to Equation (11b)
(2) Data (*22*)
(2a) Extrapolation of (*2*) according to Equation (11c)
(3) Data (*12*)
(4) Data (*18*)

Wherever ϵ has not been recorded a value 0.4 has been used.



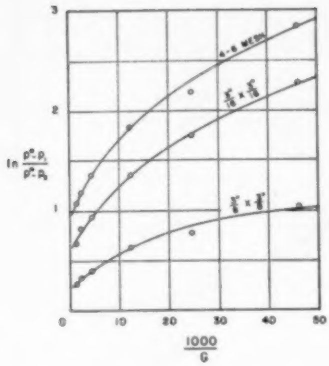


Fig. 12. Plot of $\ln \frac{p^* - p_1}{p^* - p_2}$ vs. 1/G for data (12).

According to Equation (27b), these plots should result in straight lines for systems involving piston flow of the fluid. The figure indicates that piston flow is not the case.

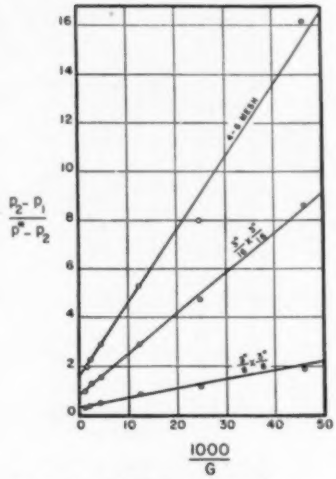


Fig. 13. Plot of $\frac{p_2 - p_1}{p^* - p_2}$ vs. 1/G for data (12).

Straight lines are obtained in accordance with Equation (27a) which indicates complete mixing of the fluid in the bed.

in the coefficient.* This difference in itself would not be too serious in that, if the latter equation demonstrates an analogy, it would then be readily accepted and even considered to be a modification of the former. The difference between these two equations, however, is not merely a readily adjustable coefficient. The J_d factor requires that there be no longitudinal mixing of the fluid, which has been shown not to be true for gas streams. In this respect Equation (29) is not limited. Its integrated forms for the limiting conditions have been shown in Equations (27a) and (27b).

* The figure 6 in the coefficient is irrelevant in the discussion since it is introduced for purposes of definition.

Whether a mass-transfer factor should contain $\epsilon/1-\epsilon$ as in Equation (29), or $1/1-\epsilon$ as in Equation (6), or some other form of dependency upon ϵ is subject to question. The answer might be given in the light of an analysis of the equations from the standpoint of fluid dynamics: by definition

$$D_p = \frac{6}{S_v} \qquad (35)$$

where S_v is the specific surface of the solids, i.e., surface per unit volume of the solids,

$$S_v = \frac{S_t}{AL(1-\epsilon)} \qquad (36)$$

S_t being the total surface of the solids in the bed and A the cross-sectional area of the empty tube. The ratio of the volume occupied by the fluid in the bed, $AL\epsilon$, to the total surface wetted, S_t, is, according to Carman (2), analogous to the definition of the hydraulic radius, r_h.

$$r_h = \frac{A\epsilon}{S_t/L} \qquad (37)$$

$A\epsilon$ being the free cross-sectional area and S_t/L the wetted perimeter. Substitution of Equations (36) and (37) into (35) leads to

$$D_p = 6r_h \frac{1-\epsilon}{\epsilon} \qquad (38)$$

Eliminating D_p from Equations (29) and (6) in favor of r_h

$$J = 6\,\frac{r_h}{L}\,\frac{\mu}{\rho D_F}\int\frac{dC}{\Delta C} \qquad (39)$$

$$J_d = \frac{1}{\epsilon}\,\frac{r_h}{L}\left(\frac{\mu}{\rho D_F}\right)^{2/3} \ln\frac{C^* - C_1}{C^* - C_2} \qquad (40)$$

It is seen that Equation (29) is in conformity with the concept of hydraulic radius, whereas Equation (6) is not. This is expected because the pressure-drop equation used in the derivation of Equation (29) employs the concept of hydraulic radius. The Kozeny equation and the Blake plot for pressure drop are similar in this respect.

Another point of controversy lies in the graphical representation of a mass-transfer factor. Gaffney and Drew recommended the plot against $D_p\rho U/\mu\epsilon$, the justification being that U/ϵ is the true average fluid velocity, u, in the packed bed. Earlier workers used the simple form $D_p\rho U/\mu$ without taking into account the effect of ϵ on the abscissa. In the present work, according to Equations (27)-(29), it is required that the J factor be plotted against $D_p\rho U/\mu(1-\epsilon)$ in order to obtain a general graphical representation. Here again the dispute is about the effect of ϵ. Eliminating D_p from these three forms of the Reynolds number and substituting u for U/ϵ will lead to

$$\frac{D_p\rho U}{\mu} = 6(1-\epsilon)\,\frac{r_h\rho u}{\mu} \qquad (41a)$$

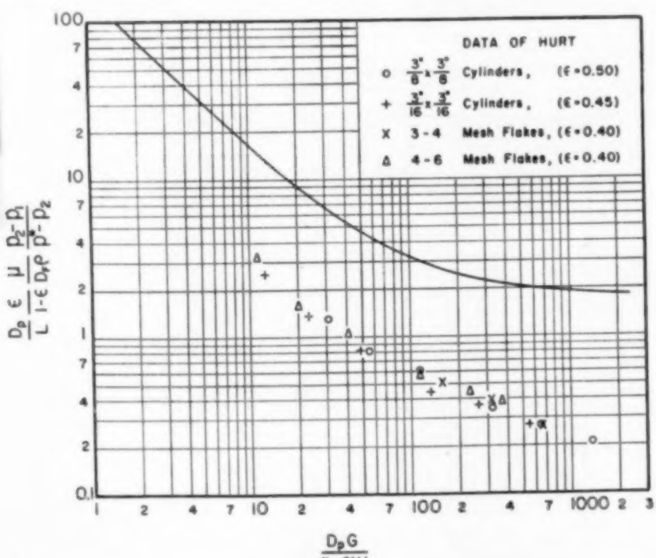


Fig. 14. Mass-transfer rates into gas streams in packed beds for systems involving complete mixing of the gas stream. Solid line is identical with those in Figs. 4-10.

$$\frac{D_p \rho U}{\mu \epsilon} = 6\,\frac{1-\epsilon}{\epsilon}\,\frac{r_h \rho u}{\mu} \qquad (41b)$$

$$\frac{D_p \rho U}{\mu (1-\epsilon)} = 6\,\frac{r_h \rho u}{\mu} \qquad (41c)$$

These transformations indicate that only the last form is in accordance with the definition of the Reynolds number using hydraulic radius (*14*).

As an aid to the comprehension of the potential application of the treatment given here, the charts shown in Figures 16-18 have been prepared for isothermal systems and/or for systems to which an average effective temperature can be assigned. In engineering calculations the desired result is often the fractional mass transfer, usually referred to as the fractional recovery, i.e., $(C_2 - C_1)/(C^* - C_1)$. Although the fractional recovery can be calculated from the J factor, a two-fold deviation in the value of this factor, for example, may amount to only a 10% change in the fractional recovery. For the sake of simplicity, substitutions of

$$X = 150\,\frac{\mu(1-\epsilon)}{D_p G} + 1.75 \qquad (42a)$$

and

$$Z = \frac{D_p}{6L}\,\frac{\epsilon}{1-\epsilon}\,\frac{\mu}{\rho D_V} \qquad (42b)$$

into Equations (*27a*) and (*27b*) and proper transformations lead to

$$\frac{C_2 - C_1}{C^* - C_1} = \frac{1}{1 + \dfrac{6Z}{X}} \qquad (43)$$

for the case of complete mixing and to

$$\frac{C_2 - C_1}{C^* - C_1} = 1 - e^{-\frac{X}{6Z}} \qquad (44)$$

for the case of no mixing.

Plots of $(C_2 - C_1)/(C^* - C_1)$ vs. the modified Reynolds numbers, $D_pG/\mu(1-\epsilon)$, with Z as parameter are shown in Figure 16 for the case of complete fluid mixing and in Figures 17 and 18 for the case of piston flow. The lines of Figure 16 are calculated from Equations (42*a*) and (43) and those of Figures 17 and 18 from (42*a*) and (44). Figure 17 covers the region of higher values for the parameter and Figure 18 covers the lower. These charts furnish a simple means of evaluating the effects of simultaneous changes in several of the process variables and in determining the optimum operating conditions.

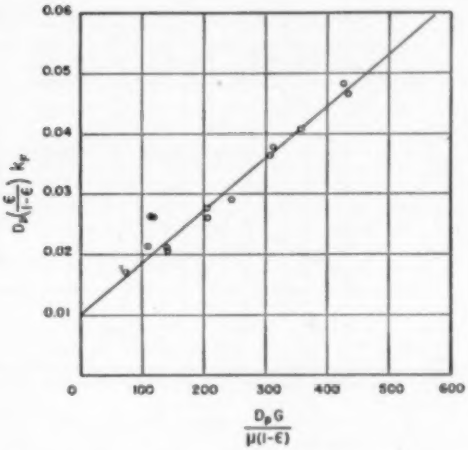


Fig. 15. Relationship of mass-transfer coefficent with flow rate.

(Data on diffusion of water into air streams (22).)

Summary

Rates of heat transfer and diffusion in flow systems are closely related to the dynamics of flow. This was first in part postulated by Osborne Reynolds. The absence of generally valid relationships in the literature for heat and mass transfer in packed systems can be attributed to the lack of knowledge of fundamental relationships in fluid flow in packed beds and to a widely accepted misinterpretation of Reynolds' argument. In a previous article (*7*) fluid flow in packed columns was studied and fundamental equations developed. In the present work, the existence of analogies between mass-transfer rate and pressure loss has been demonstrated and general equations formally relating mass-transfer rate to variable pertaining to packed columns have been developed.

Relatively simple equations have been derived for the mass-transfer factor, the mass-transfer coefficient and the fractional recovery of solutes for isothermal systems and/or for systems to which an average effective temperature can be assigned.

Acknowledgment

It is a pleasure to acknowledge the encouragement and advice given the author by H. H. Lowry and J. C. Elgin, and the assistance rendered by Curtis W. DeWalt, Jr., in preparing this manuscript.

Notation

a, a', a'' = coefficients in Equations (13), (12), and (14), respectively

A = cross-sectional area of the empty column

b, b', b'' = coefficients in Equations (13), (12), and (14), respectively

c = specific heat of fluid

C = concentration of solute in main stream

C^* = equilibrium concentration of solute in stream

D = diameter of column

D_V = coefficient of diffusion

D_p = effective diameter of granular solids as defined by Equation (35)

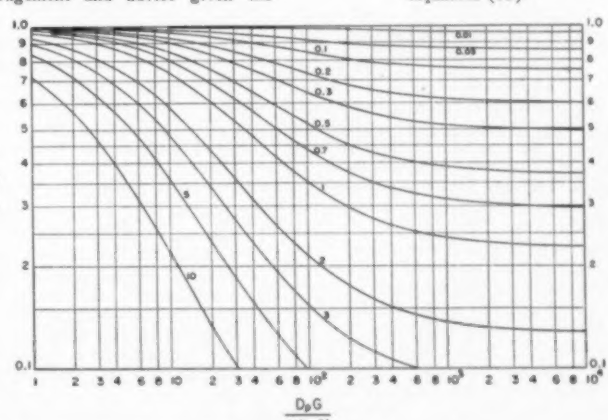


Fig. 16. Mass-transfer rates into fluid streams in packed beds involving complete mixing of fluid. Chart prepared from Equations (42a) and (43) for values of Z, the parameter, from 0.01 to 10.

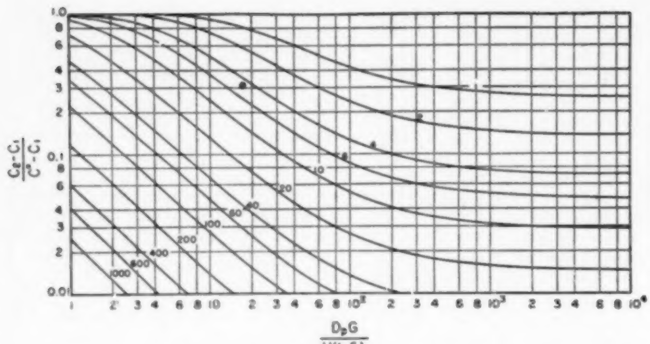


Fig. 17. Mass-transfer rates into fluid streams in packed beds involving no longitudinal mixing of fluid. Chart prepared from Equations (42a) and (44) for values of Z, the parameter, from 1 to 1000.

f_k = friction factor as defined by Equation (28)

$G = \rho U$, the mass flow rate of fluid per unit cross-sectional area of empty column

h = coefficient of heat transfer

H = heat transfer rate per unit area of transfer surface

H_T = height of a transfer unit as defined by Equation (10)

J = new mass-transfer factor as defined by Equation (29)

J_d = mass-transfer factor as defined by Equation (5)

k = thermal conductivity of fluid

k_g = coefficient of mass transfer

L = height of packed bed

M_m = mean molecular weight of fluid stream

$N_{Re} = \frac{D_pG}{\mu}$, Reynolds number

N_t = number of transfer units as defined by Equation (8)

p = partial pressure of solute in gas streams

p^* = vapor pressure of solute

P = absolute pressure in column

r_h = hydraulic radius for packed bed as defined by Equation (37)

R = resistance offered to fluid flow (Equations (13) and (15b))

$Sc = \frac{\mu}{\rho D_v}$, Schmidt number

S_t = total geometric surface area of solids in bed

S_v = specific surface of solids, i.e., surface per unit solid volume

t = temperature of fluid

t^* = temperature at solid-fluid boundary

u = actual average velocity of fluid stream

u_m = u calculated at average of end pressures

u_B = fluid velocity at boundary between eddy and laminar layers

$U = u\epsilon$, superficial fluid velocity based on empty column

U_m = U calculated at average of end pressures

w = mass-transfer rate per unit transfer area (Equations (14) and (15c))

X = dimensionless parameter (Equation (42a))

Z = dimensionless parameter (Equation (42b))

γ = proportionality constant of Equation (17), dimensionless

$\Delta C = C^* - C$, at any section

ΔC_{LM} = log mean ΔC as defined by Equation (4)

$\Delta P = P_2 - P_1$, pressure loss in column

ϵ = fractional void volume in packed bed

λ = proportionality constant of Equation (16), dimensionless

μ = absolute viscosity of fluid stream

ρ = density of fluid

Subscripts 1 and 2 designate entrance and exit conditions, respectively.

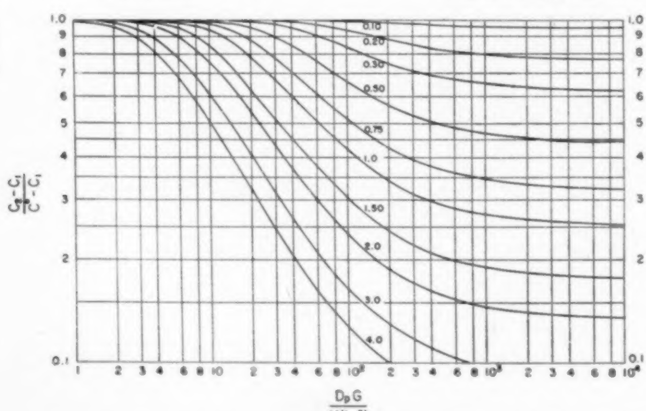


Fig. 18. Mass-transfer rates into fluid streams in packed beds involving no longitudinal mixing of fluid. Chart has been prepared from Equations (42a) and (44) for values of Z, the parameter, from 0.1 to 4.

Literature Cited

1. Arnold, J. H., *Physics*, **4**, 255 (1933).
2. Carman, P. C., *Trans. Inst. Chem. Engrs. (London)*, **15**, 150 (1937).
3. Chilton, T. H., and Colburn, A. P., *Ind. Eng. Chem.*, **26**, 1183 (1934).
4. Colburn, A. P., *Ibid.*, **22**, 967 (1930).
5. Colburn, A. P., *Trans. Am. Inst. Chem. Engrs.*, **29**, 174 (1933).
6. Ergun, S., and Orning, A. A., *Ind. Eng. Chem.*, **41**, 1179 (1949).
7. Ergun, S., *Chem. Eng. Progress*, **48**, 89 (1952).
8. Gaffney, B. J., and Drew, T. B., *Ind. Eng. Chem.*, **42**, 1120 (1950).
9. Gamson, B. W., Ph.D. Thesis, University of Wisconsin (1942).
10. Gamson, B. W., Thodos, G., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **39**, 1 (1943).
11. Hobson, M., and Thodos, G., *Chem. Eng. Progress*, **45**, 517 (1949).
12. Hurt, D. M., *Ind. Eng. Chem.*, **35**, 522 (1943).
13. International Critical Tables, Vol. III, p. 207, McGraw-Hill Book Co., Inc., New York (1928).
14. McAdams, W. H., "Heat Transmission," pp. 118, 167, McGraw-Hill Book Co., Inc., New York (1942).
15. McCune, L. K., and Wilhelm, R. H., *Ind. Eng. Chem.*, **41**, 1124 (1949).
16. Nusselt, W., *Z. Ver. deut. Ing.*, **21**, 1750 (1909).
17. Prandtl, L., *Z. Physik.*, **11**, 1072 (1910).
18. Resnick, W., and White, R. R., *Chem. Eng. Progress*, **45**, 377 (1949).
19. Reynolds, Osborne, "Papers on Mechanical and Physical Subjects," Vol. I, p. 81, Cambridge University Press (1900).
20. Sherwood, T. K., "Absorption and Extraction," p. 31, McGraw-Hill Book Co., Inc., New York (1937).
21. Taecker, R. G., and Hougen, O. A., *Chem. Eng. Progress*, **45**, 188 (1949).
22. Wilke, C. R., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **41**, 445 (1945).

QUESTIONS ASKED BY ENGINEERS

On Employment and Careers

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WHY is it that engineers when facing technical problems will use all their analytical techniques, but when it comes to social or economic problems, will abandon the analytical skills of the engineering approach?

Decisions affecting a future way of life need all the skills and consideration that one can muster. A real problem facing graduating engineers is a choice of jobs or a choice between a job and graduate work. Too often these decisions are made haphazardly; the student has not had the initiative to find out as much as he could about the various opportunities befitting his abilities and talents. The American Institute of Chemical Engineers, through its Student Chapter Committee, proposes an active program on "Employment and Careers," and will welcome discussion on its various problems.

In a recent article on employment and careers for mechanical engineers, R. E. Peterson presented a set of answers to an American Society of Mechanical Engineers student query of 13 questions (*9*). Discussions of this type can do much toward encouraging students to think about the decisions they need to make following their graduation, though for many, the military program will lead to an effective postponement in their choice of a career. The set of questions below has been prepared for chemical engineering students and each question is discussed briefly so as to suggest expansion by the student chapter programs. No pat answers or lofty advice should be applied, and neither should students be led. The questions and answers should stimulate further discussions on the importance of making the right decision in selecting a job.

What are the job opportunities? Job opportunities are excellent, for the supply of engineers falls considerably short of even minimum demands. Surveys made by the Engineering Manpower Commission of the Engineers' Joint Council (*5*) strongly emphasize the critical shortage of engineers. Unfortunately, almost half the June, 1951, class of about 38,000 engineering graduates was claimed by the R.O.T.C. and reserve programs, and by the Selective Service System. For the remaining 19,000, there were some 80,000 job opportunities, exclusive of military needs. Thus the actual unfilled demand is more than 60,000; and the situation is expected to become steadily more critical in the next few years, for graduating classes will undergo marked reductions. Present estimates of graduates are 26,000 in 1952; 17,000 in 1953; and only 12,000 in 1954.

From these figures relating to the shortage of engineers, the situation pertaining specifically to chemical engineers is even more acute. Chemical industry has been growing at a much more rapid rate than any other industrial branch. Lux (*8*) estimates that the shortage of chemical engineers is at least 12,000, and in the next three years might conceivably rise to a high of 25,000. Instead of meeting this shortage by interesting more students in the field, the per cent enrollment in chemical engineering compared to other branches of engineering indicates a downward trend (*8*).

What are present salary starting offers? Understanding of the present market is rather involved. Although the supply of engineers is becoming increasingly short, starting salaries must be aligned with wages now being paid to present employees. On the other hand, some companies with government research and development contracts find it necessary to pay higher wages to attract the desired number of engineers. Operations dependent upon military and A.E.C. funds are considered, in some instances, to be relatively short-lived. Thus, as expected, a considerable range of starting salaries is to be found. However, an intelligent applicant will consider, in addition to salary, other features such as the attractions of a stable operation, future opportunities, type of job, location and climate, and fringe benefits. The following set of salaries may be considered typical, with the upper limits being paid by organizations working on government contracts or for a 6-day week: B.S., $325 to $350, M.S., $350 to $400 (including some 5-yr. B.S.'s), and Ph.D.'s $475 to $550.

What are salary expectations? Salary surveys are often presented to indicate the general trend of salaries with years of experience. The same critical judgment should be exercised in interpreting salary surveys as is applied in evaluating an engineering test or experiment. For example, the engineer should inquire how the salary data were obtained and correlated, were supervisors included, how years of experience were interpreted? With this note of caution, some results of the Los Alamos 1950 National Survey of Professional Scientific Salaries are presented in Figures 1 and 2 (*12*). This survey, though now relatively old,* is noteworthy in that

* Los Alamos has released results of its 1951 survey (*13*), indicating similar trends.

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in the survey of some 27,000 professional scientific personnel employed in research and development laboratories, no employees with major supervisory or administrative responsibilities were included. The inclusion of supervisor salaries, typical of many surveys, would have distorted the general findings.

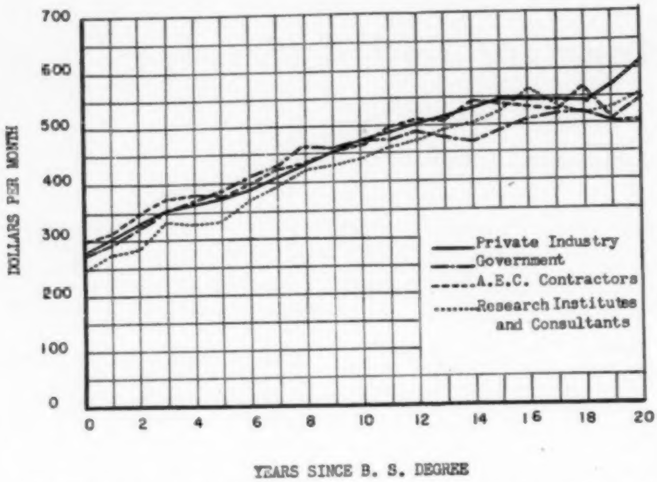


Fig. 1. Comparison of B.S. salaries by general field of employment (1950 National Survey of Professional Scientific Salaries) *(12)*

TABLE 1.—DISTRIBUTION OF CHEMICAL ENGINEERING GRADUATES

General	%	Type of Industry	%	Function	%
Manufacturing	82	Chemical and Allied Industries	45	Technical Administration	32
Personal Services (including consulting)	7	Petroleum	17	Development	17
Education	5	Food Products	4	Applied Research	14
		Rubber	4	Design	11
		Iron and Steel	3	Teaching	5
				Operation	3
				Consulting	2.6

TABLE 2.—FUNCTION OF ENGINEERS IN PRIVATE EMPLOYMENT

	Ph.D.	M.S.	B.S.
Administration-technical	29.2	30.1	29.1
Design	7.4	14.8	17.3
Development	10.0	10.7	9.3
Research, applied	19.9	10.8	5.5
Research, basic	2.2	0.8	0.2
Sales	1.2	2.6	5.9

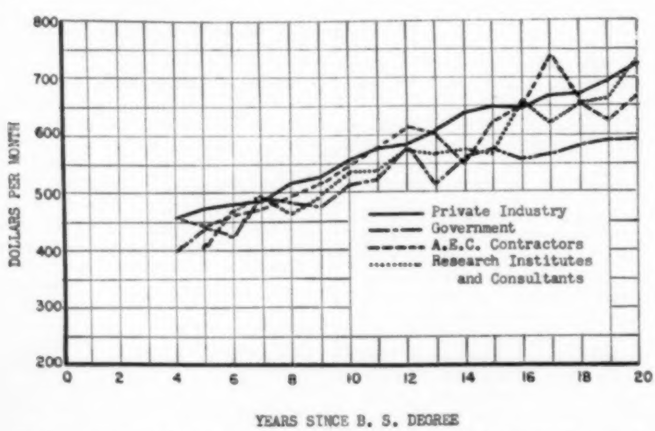


Fig. 2. Comparison of Ph.D. salaries by general field of employment (1950 National Survey of Professional Scientific Salaries) *(12)*

Figure 1 is the comparison of B.S. (including M.S.) salaries for scientific personnel in the fields of employment designated as private industry, government, A.E.C. contractors, and research institutes and consultants. The weighted least square line for the combined fields of employment is: Dollars a month = 303.35 + 15.21 (years since B.S. degree).

A similar set of curves is presented for Ph.D. salaries in Figure 2. The weighted least square line† for the Ph.D.'s is: Dollars a month = 387.86 + 15.32 (years since B.S. degree). The salary differential between the Ph.D. and B.S. is practically constant and represents about $85 a month. The figures indicate that for both B.S.'s and Ph.D.'s, salaries are generally high for private industry, whereas government salaries tend to be low after B.S. plus 10 years.

Other interpretations of the survey were that the geographical influence on B.S. salaries was probably not so important as the factors of size and type of industry; and salaries are somewhat higher in large research staffs (more than 500) and lower in the smaller ones (25 to 50 category). The survey should be consulted for more specific data on types of industries and other conclusions.

Figures 1 and 2 represent salaries for scientific personnel employed only in research and development. In considering a salary future it must be remembered that, in the past, industry placed greater value on organizing ability than on technical ability. The money-earners have been the supervisors and executives, and not the research men. This emphasis will probably continue, even though there is a trend in some companies to pay due rewards for technical achievements.

What types of jobs are available? This question can be answered in part by presenting a general picture of the distribution of chemical engineers in industry. Tables 1 and 2 are taken from Sherwood's discussion on "What do chemical engineers do after they leave college?" *(11)* These figures were mainly derived from a 1946 survey and do not include recent expansions in atomic energy work, jet propulsion and guided missile work, etc.

Is graduate work recommended? Two extremes may be given. There is but one answer for students who are capable and have a genuine interest in research: graduate work is strongly recommended. An examination of Table 2 reveals that the percentage of Ph.D.'s

† Though it may be customary to represent the salary data by a straight line, the actual data lie above the weighted least square line in the middle portions, and below at the two ends.

in applied research is about twice that of the M.S., which, in turn, is about twice that of the B.S. The ratio of the percentages is even higher for the field of basic research. In contrast, students whose abilities are more strongly focussed upon gaining financial advantage would do equally well without taking graduate work. It is interesting to note that the opportunity of becoming an executive does not appear to be enhanced by obtaining advanced degrees, as shown by the nearly equal percentages listed for administration-technical.

Actually, many students will not know which choice will be to their best interests. Interviews with the college staff and employers will help formulate decisions, and certainly participation in student chapter programs on this subject will help to clarify the issues. A balance needs to be made of the monetary returns and of the satisfactions to be derived from the type of work. For example, from a purely practical approach, the economic advantage of an M.S. degree has not been established; however, it is well to note that the additional training in the fundamentals and in the special fields well may prove to be of marked technical advantage, and can lead to increased pride in accomplishments.

How does one choose a job? Whereas, in past years, the emphasis was on getting *a* job, the present situation brings its problems on *what* job to accept. The choice of positions will be a major decision, but probably not so important as choosing a wife, as Bailar points out. His advice (*1*) is to be honest with yourself and try to weigh accurately the combination of talents that you do possess. Figure 3 serves to illustrate the general approach for self-appraisal and suggests the types of jobs to match one's skills. It is not the intent that the diagram be taken too literally. An excellent set of discussions on job careers which will be of considerable aid to seniors appeared in *Chemical and Engineering News* in 1950, and is now available in book form, "Careers in Chemistry and Chemical Engineering," published by the American Chemical Society.

Although the emphasis of this answer has been on the evaluation of one's skills, other factors mentioned previously, such as salary and job opportunities, will play important roles in the selection of a job.

How do employers look upon grades and outside activities? Good grades will always be desirable and are to be encouraged, but not at the expense of complete absorption in school work. Most progressive companies will not consider grades alone as the determining basis for offering a student a job. They are interested in evaluating students by their performance in school work along with other interests and activities. A proper balance in distributing effort in academic studies, activities and outside interests will be to the best interest of the student.

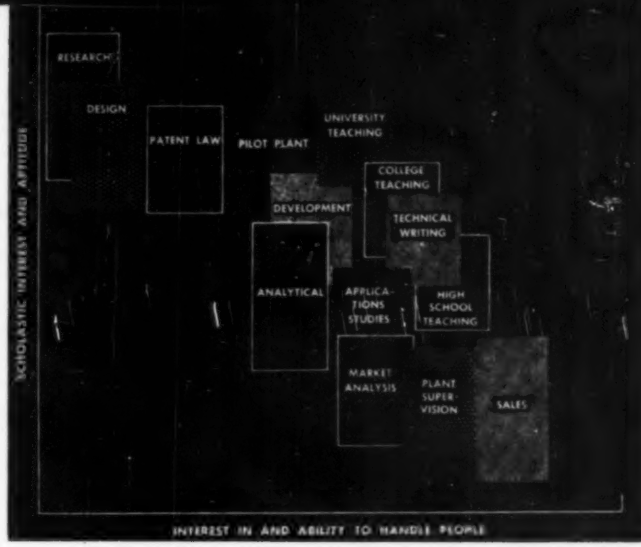
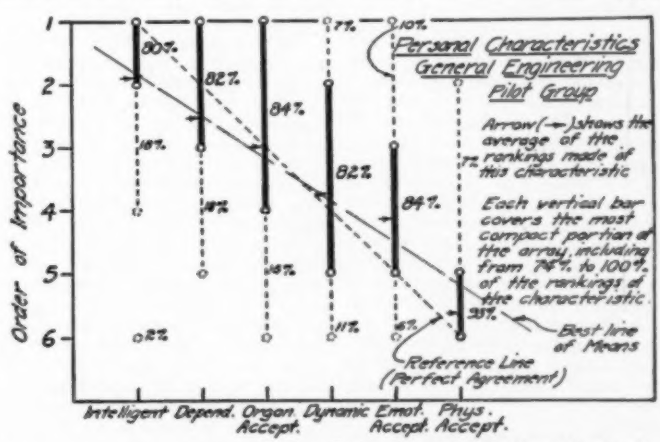


Fig. 3. Interest in and ability to handle people. (*1*)

What do employers look for? "The employer wants an employee who possesses the physical, mental and personal qualities essential to a satisfactory completion of the task for which he is hired." Scott (*10*) recognizes that this answer is more easily stated than accomplished. Positions may involve technical, administrative, supervisory, and sales abilities. In many such cases, the nature of the requirements for the position is sufficiently complex to overrule any one qualification as being the determining factor. In fact, even after the personal interview, receipt of transcript and letters of recommendation, the employer may still have to guess the candidate's possibilities. The employer and the student as well should try to minimize the extent of the gamble involved in job selection and acceptance.

It is of interest to note what personal characteristics were considered most desirable by executives for certain types



Courtesy; Engineers' Council for Professional Development.

Fig. 4. Executive rating of desirable personal characteristics for general engineering. (EPCD Subcommittee on Student Development, September, 1948 (*3*).) The major personality groups are in accordance with the ratings. For example, 80% of the respondents listed "intelligent" as their first or second choice, and 93% listed "physically acceptable" as their fifth or sixth choice. Each of the six characteristics per group is listed in order of its mean rating.

of positions. An approach to the problem of exploring and analyzing opinions on personal characteristics for engineers was carried out by the Subcommittee on Student Development of the Engineers' Council for Professional Development (*3*). The survey was made with "the purpose of sensitizing the younger men to the opinions which their future employers entertain about matters of personality." Six groups were chosen to represent the main personality characteristics: organizationally acceptable, emotionally acceptable, physically acceptable, dynamic (professionally energetic, drive), dependable, and intelligent (mentally endowed). These groups were rated one to six (one being first choice) for general engineering and for four functional subdivisions: research and invention, design and construction, production and management, sales and distribution. Each of the major groups contained six characteristics which were in turn rated from one to six. Ratings were made by executives, administrators, faculty, personnel officers and student groups. Figure 4 represents the results of the ratings by executives for general engineering. The personality groups considered most desirable are: intelligent, dependable, organizationally acceptable and dynamic, and the most desirable applicants are clear-thinking, imaginative, truthful, reliable and cooperative. The report should be consulted for discussion of the other ratings.

As Scott points out, it will be to the best interests of the student if he seeks a job with "complete naturalness and sincerity." In this way an employer can readily determine the applicant's personal characteristics.

How do large companies compare with small ones as places to work? The general impression that students usually acquire is that in working for a large company, the engineer loses his identity and becomes one of the mass. Actually, this should be far from reality, for it is definitely to the advantage of any size company to know and keep tab on the "promising young men." Company size in most cases need not be a determining factor in job selection. Probably more important than *size* of company is the *spirit* of the company. It is important for the student to discover as much as he can about the spirit of the company. Typical questions that the student should ask are as follows: (*1*)

Are the technical men happy in their work?
Do they enjoy the company of each other?
Are their wives happy?
What is the rate of turnover in the technical group?

What are the advantages of a company training program? For some students who have not formulated specific job interests, company training programs will be found to be of definite advantage in clarifying their concepts of research, development, manufacturing, etc. Many industries have found that the system of rotating assignments during the first years is a sound program in attempting to place the right man in the right job.

What does industry expect from the engineering graduates? A measure of success will be the ability to "get things done." Furthermore, the manner of accomplishment is important: industry demands that its engineers get things done in a manner largely dictated by the economic nature of the assignment. Objectives of the assignment may be long-range, but most commonly are short-range, for seldom can industry afford the luxury of a research and development program keyed to detailed perfection. An appreciation of factors of the assignment formulation, "what, how, who and when," and experience in execution are the kinds of training that students will do well to acquire (*6*). Schools may teach only engineering competence, which is just one of the qualities needed to get a job done. Thus, the transition from an academic environment to an industrial exploitation may not always be smooth.

What are some aids for professional development? Participation in one's professional societies is one of the important steps in professional development. In fact, many companies recognize that it is to their own advantage to encourage their engineering employees to participate in the programs of the local sections and national Institute. Students now have the opportunity of becoming student members in the A.I.Ch.E., and through their student chapter and local A.I.Ch.E. section can take advantage of the professional guidance and inspiration offered by the programs and publications of the Institute. Student membership facilitates and encourages the transition to Junior membership. The growth in the strength and importance of the Institute will be dependent largely upon the support and interest engendered in the students and young graduate engineers. An important guide for development during the early years of an engineer's life has recently been published by Engineers' Council for Professional Development as part of the work of the Training Committee (*4*).

What are the engineer's obligations to society? Society expects more than just a technical performance from the engineer starting his professional career. Though one might consider his performance to be of little or no consequence toward improving our way of life, there exists, certainly, a strong challenge for men of vision and courage. Prof. W. K. Lewis once pointed out that "in the early days of our country, the primary function of the engineer was to increase production, while today the engineer not only must do this but also must deal effectively with the human problems of industry which are currently its most important and difficult problems (*7*)." An engineer can make more worthy contributions to society if he views the needs of society as a whole rather than if he confines his perspective to special interests. In regard to the professional conduct expected of engineers, the student will find in the "Canons of Ethics for Engineers" and in the Code of Ethics of the A.I.Ch.E., that the recognition of ethics is not to be passive, but is to be a dynamic set of principles guiding his conduct and way of life (*2*). Simple, but inspiring, is the engineer's pledge (in the "Faith of the Engineers") to carry out his obligations to serve humanity with complete sincerity (*2*).

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Literature Cited

1. Bailar, J. C., Jr., *Chem. Eng. News*, **28**, 2959 (1950).
2. Engineers' Council for Professional Development, 18th Annual Report (Sept. 30, 1950).
3. Engineers' Council for Professional Development, Subcomm. on Student Development, ". . . The Most Desirable Personal Characteristics . . . ," (September, 1948).
4. Engineers' Council for Professional Development, Training Comm., "First Five Years of Professional Development" (1950).
5. Engineers' Joint Council, *Eng. Manpower Newsletter* (June 28, 1951).
6. Kellog, D. S., *Mech. Eng.*, **73**, 572 (1951).
7. Killian, J. R., Jr., *M.I.T. Tech. Review* (July 1951).
8. Lux, J. H., *Chem. Eng. News*, **29**, 2822 (1951).
9. Peterson, R. E., *Mech. Eng.*, **73**, 487 (1951).
10. Scott, S. L., *Chem. Eng. News*, **28**, 2890 (1950).
11. Sherwood, T. K., *Chem. Eng. News*, **28**, 2648 (1950).
12. "1950 National Survey of Professional Scientific Salaries," Los Alamos Scientific Laboratory, Univ. Calif., Los Alamos, N. M.
13. "1951 National Survey of Professional Scientific Salaries," Los Alamos Scientific Laboratory, Univ. Calif., Los Alamos, N. M., *Chem. Eng. News*, **30**, 518, (1952).

PRESSURE LOSS

In Centrifugal Entrainment Separators Under Vacuum

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This paper gives the results of an experimental study of the pressure drop through centrifugal entrainment separators operating under vacuum. Data are presented for fatty acid vapor, water and glycerine vapors at 100-200 ft./sec. in units ranging from 1-in. inlet diam. to 20 in. Data were obtained on units of 1-, 2- and 3-in. inlet diam. (3-, 6- and 9-in. shell diam.) operating on fatty acid vapor. In addition pressure losses on 16- and 20-in. units in use on factory glycerine evaporators and glycerine stills have been included to extend the size range covered in this study.

IN the course of a study of fatty acid distillation and distillation equipment, an investigation was made of centrifugal separators for removing entrained nonvolatile liquid. Cyclone collectors similar to those used for dust collection (Fig. 1a) and an inverted cyclone developed by Webre (*5*), (Fig. 1b) have been used extensively for the removal of liquid entrainment. About 14 years ago the late M. H. Ittner instituted the use of a further modification (Fig. 1c). A large part of the present study was carried out using the latter units. In addition to data on small separators of the Ittner design employed in fatty acid distillation, measurements of pressure loss in larger units employed on glycerine evaporators and glycerine stills are included here to extend this study over a wide range of sizes.

Experimental

Fatty Acid Distillation. A simplified diagram of the fatty acid distillation pilot plant which was used for most of the test work is shown in Figure 2. Crude fatty acids were supplied to the still at constant rate by a Proportioneer's plunger pump. After preheating by 150 lbs./sq.in. steam the acids entered a Dowtherm-heated vaporizer in which the outlet temperature was held constant. (±2° C.). Approximately 95% of the feed vaporized and the mixture of vapor and liquid entered the first separator through the tangential inlet. Here most of the unvaporized liquid was removed while the vapor passed on to Separator B. This second separator during much of this study was a large vessel 2 ft. in diam. by 6 ft. high from which the clean vapor passed to the condenser. The small vapor line passing from the test separator ended at this point, and, as will be discussed further, acoustic velocity was found to occur here.

In the operation of the pilot plant, feed and product rates were checked hourly by weight. The absolute pressure at the points indicated was measured by either a Dubrovin gauge or a simple absolute pressure manometer. To insure steady-state conditions, each run was started after constant feed and distillate rates and constant temperature had been obtained as shown by weight readings and by a strip chart recorder. A steady 4-hr. period was used for the run during which weight, pressure and temperatures were recorded each hour. To prevent condensation of fatty acid on the separator walls or in the vapor lines, electrically heated jackets were provided and manually controlled by variable transformers. In general, the jacket was maintained about 10° C. above the condensing temperature of the vapor. Experimental data are tabulated in Table 1.

Details of the small test separators used in the fatty acid distillation pilot plant are shown in Figure 3. Figure 3a shows a 3-in. inlet Ittner unit, its associated piping and points of temperature and pressure measurement. Figure 3b shows a 3-in. inlet cyclone (inverted Webre) which was made from the 3-in. Ittner and substituted for it with the same piping arrangement. In Figure 3c and 3d the details of a 2-in. inlet diameter Ittner unit and a 1-in. Ittner are shown.

Glycerine Distillation. To provide a basis for evaluating pressure-loss relations developed from the pilot plant data, measurements were made on large separators in service on production glycerine stills. Crude glycerine (approximately 84% glycerine, 7% salt, 7% water and 2% organic nonvolatiles) is fed continuously to the still pot where heat is supplied by closed steam coils and the liquid is agitated by open steam. Only liquid spray passes through the centrifugal separator along with the vapor, in contrast to the fatty and distillation pilot plant where all the nonvolatile liquid leaves the vaporizer with the vapor. Since the collected entrainment is

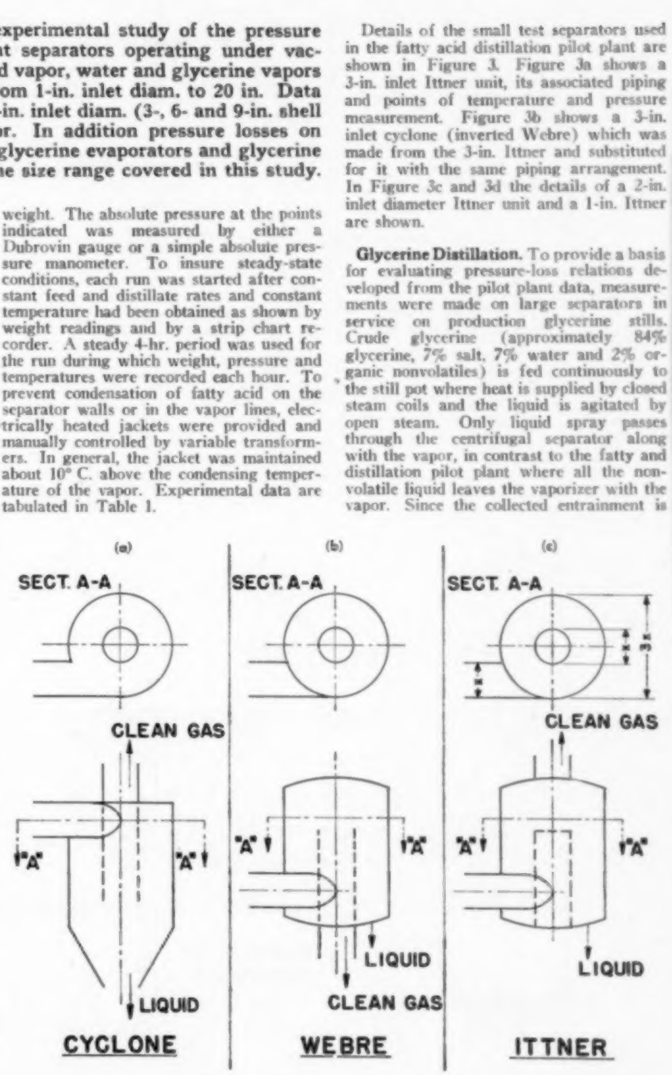


Fig. 1. Types of centrifugal separators.

TABLE 1.

Separator	Run No.	Kind of Vapor	Feed lb./hr.	Vapor Rates lb./hr. Fatty Acid	Vapor Rates lb./hr. Glycerine	Vapor Rates lb./hr. Water	Bottom lb./hr.	% OH	Pressure in mm.Hg.abs. Except as Noted P_0	P_1	P_2	Temperature T_1 °C.	T_2 °C.	Linear Velocity ft./sec. at P_1	at P_2	From Table 3 N_s
1-in. diam.	20A		30.3	25.0			5.2	82.9		21.0	8.9	269		110	261	9.3
inlet	20C	Tallow	50.0	39.8			10.1	79.8		33.0	13.4	275		112	276	9.1
Ittner	20D	Fatty Acid	60.5	47.4			12.8	78.8		40.5	15.7	272		109	280	10.0
	20E	Mw. 274	75.0	57.2			17.2	76.9		45.5	18.6	281		118	289	8.1
	20F		78.0	64.4			18.0	76.9		45.0	19.5	279		124	282	7.0
																Avg. 8.7
2-in. diam.	106	Oleic	104	100			4.3	97.0	16.7		5.3	242	242	137	395	3.4
inlet	106A	Acid	173	167			7.3	96.7	31.4		8.6	257	264	126	418	4.9
Ittner	106B	Mw. 282	249	241			8.1	97.5	40		12.5	263	269	138	399	3.5
	108	Tallow	127	120			7.0	94.5	23.7		6.4	252	260	131	[illegible]	6.4
	109–1	Fatty Acid	129	123			6.4	95.7	20.5		6.1	248	255	147	442	3.9
	109–2	Mw. 274	112	106			5.8	93.1	31.6		27.*	254	261	82	96	5.4
																Avg. 4.6
3-in. diam.	99C		74.4	72			1.8	97.8	6.7		4.2	221	233	104	163	5.0
inlet	99D	Oleic	135	129			5.6	95.8	12.4		7.5	235	248	100	166	6.7
Ittner	99E	Acid	162	156			5.5	96.7	14.2		8.9	240	254	106	169	4.9
	99F	Mw. 282	190	185			5.4	97.2	17.4		11.0	243	259	101	170	6.0
	100		298	289			9.1	97.0	25.6		16.2	252	276	109	172	5.2
	101	Tallow Mw. 274	150	136			13.6	91.0	12.6		7.6	239	253	112	174	5.7
																Avg. 5.6
16-in. diam.	201	Water				5459			25.5-in.Vac.		26.4-in.Vac.(180° F.)			232	298	10.2
inlet	202	from				6670			25.0		26.4			254	362	11.2
Ittner	203	Evaporator				6850			23.6		24.6			204	243	10.2
																Avg. 10.5
20-in. diam.	601	Glycerine			1742	391				11.4	8.8 (300° F.)			190	246	7.3
inlet	602	from			1902	505				13.6	11.2			192	233	6.3
Ittner	603	Still			2007	414				13.3	11.1			182	218	5.8
																Avg. 6.5
3-in. diam.	103	Oleic	100	96			4.2	95.8	11.0		6.3	226	237	82	145	12.5
inlet	103A	Acid	196	190			6.4	96.0	21.0		11.4	241	255	88	188	12.1
Cyclone	103B	Mw. 282	304	295			9.1	97.2	33.4		....	252	266	87	...	13.2
																Avg. 12.6
16-in. diam.	301	Water				6517			22.4-in.Vac.		24.7-in.Vac.(180° F.)			177	234	21.9
inlet	302	from				6974			23.6		26.7			204	415	16.9
Webre		Evaporator														
																Avg. 19.4
16-in. diam.	501	Glycerine			1210	379				20.4	16.0 (300° F.)			141	180	12
inlet	502	from			1139	379				18.8	14.2			152	201	14
Webre		Still														
																Avg. 13
16-in. diam.	401	Water				7500			8.0-in.Abs.		6.0-in.Abs.(180° F.)			168	224	19.6
inlet	402	from				6600			6.4		5.2			183	226	16.6
Cyclone	403	Evaporator				6800			7.1		5.9			187	206	15.6
(60-in. shell)	404					7600			6.1		3.6			223	378	14.5
	405					7500			6.2		4.1			216	327	14.5
																Avg. 16.2

* In Run 109-2 static pressure was raised by loading vacuum jets.

continuously returned to the still pot, it was not possible to measure it. During a period of steady normal operation, the weights of feed and condensed glycerine were measured. The open steam rate was determined by the upstream pressure on a calibrated orifice. The absolute pressures on either side of the centrifugal separators under test were measured with a Dubrovin gauge. Since the unit has no thermometer, the temperature was estimated. One unit tested was a 16-in. inlet diam. Webre separator (Runs 501 and 502). There were no extra fittings between the pressure taps. The other unit was a 20-in. inlet diam. Ittner (Runs 601, 602 and 603) which included a 90° elbow between the pressure taps. Runs 501, 502 and 603 were made with crude glycerine of the approximate composition just mentioned, Runs 601 and 602 with once-distilled 98.5% glycerine.

Glycerine Evaporators. Additional data were obtained from factory reports on glycerine evaporators in which water is removed from a dilute glycerine solution. The entrainment is returned to the evaporator continuously and is not measured. One system for which data were available was in the Jersey City plant and had a 16-in. inlet Webre in series with a 16-in. Ittner. At a later date new data were taken on the same system with the Webre removed. In the latter case (Runs 201, 202 and 203) there were the following pipe and fittings between the pressure taps: one sudden contraction to 16-in., 1-90° elbow, 7½ ft. of pipe, the Ittner separator, another 90° elbow, 14 ft. of pipe. In the former case (Runs 301 and 302) there was 1-90° elbow and the Webre separator in addition to the items just listed.

Data were available also on an evaporator in the Kansas City plant which included a 16-in. inlet cyclone with a 60-in. diam. shell (1 to 3.67 instead of 1 to 3 as for Webre and Ittner units). Two sets of runs were made with this system. In Runs 401, 402 and 403 there were the following pipe and fittings between the pressure taps: one sudden contraction to 16-in., 1-90° elbow, 1 tee, 24 ft. of pipe and the separator under test. In Runs 404 and 405 there were 3-90° elbows, 1 tee, 5 ft. of pipe and one gate valve (wide open) in addition to the items just listed.

Comment on Results

Linear Velocity. Experimental data are shown in Table 1 for the different kinds and sizes of separators tested. From these the linear vapor velocities were calculated and entered in the table. Where the upstream pressure was measured at P_o, this same pressure was used to calculate velocities at P_1 since this is satisfactory for a visualization of the flow conditions. In the case of the 2-in. separator (Runs 106-109-2), the measured pressure at P_2 is in a 3-in. line. The pressure was, therefore, corrected so the velocity at P_2 is that at the end of the 2-in. line.

Examination of these velocities for fatty acid distillation runs 20A-20F shows them to be essentially constant over the entire range of mass vapor rates. This same observation may be made with respect to Runs 106-109-1 and 99C-101. Further consideration of the reason for the lack of variation in

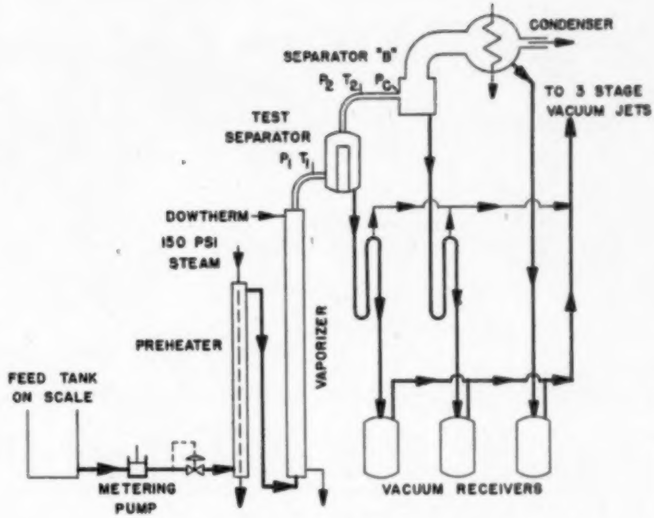


Fig. 2. Flow diagram of pilot plant fatty acid still.

TABLE 2.—VAPOR RATE LB./(SQ.FT.)(SEC.) AT P_2 CALCULATED FOR 3-IN. DIAM. PIPE, 26 FT. LONG WITH ACOUSTIC VELOCITY AT OUTLET VS. MEASURED VAPOR RATE

Run	Stock	Pressure P_2 mm.Hg.abs.	Measured Vapor Rate lb./hr.	Measured Vapor Rate lbs./(sq.ft.)(sec.)	Calculated Vapor Rate lb./(sq.ft.)(sec.)
99C	Red Oil	4.2	72	0.390	0.415
99D	MW. 282	7.5	129	0.698	0.745
99E		8.9	156	0.844	0.882
99F		11.0	185	0.995	1.09
100		16.2	289	1.56	1.60
101		7.6	136	0.74	0.75
102		6.0	100	0.54	0.60
102A		10.9	193	1.04	1.08
102B		16.0	294	1.59	1.59

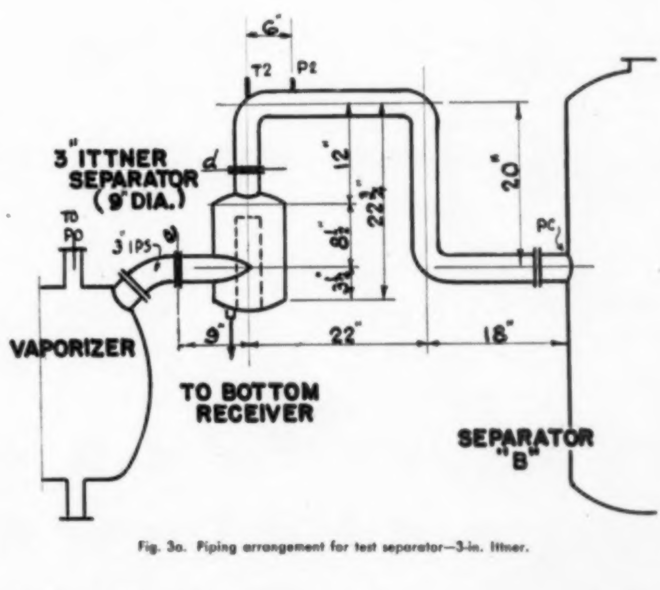


Fig. 3a. Piping arrangement for test separator—3-in. Ittner.

TABLE 3.

Run No.	Mass Velocity of Vapor lb./(hr.)(sq.ft.) G	$G_{a\,crit}$	$G_{i\,crit}$	$G/G_{a\,crit}$	$G/G_{i\,crit}$	P_2/P_o	P_2/P_1	$N=4fL/D$	$Re\times10^{-3}$	f	Known Resistance in ft. L_k	Known Resistance in Vel. Hds. $N_k=4fL_k/D$	Separator Resistance in Vel. Hds. $N_s=N-N_k$	Separator Resistance in pipe diam. $L_s/D=N_s/4f$
20A	1.16		2.70		.430		.424	10.5	15.6	.0079	3.4	1.2	9.3	290
20C	1.85		4.25		.435		.406	10.2	24.0	.0070	3.4	1.1	9.1	330
20D	2.21		5.22		.423		.388	11.0	28.7	.0067	3.4	1.0	10.0	370
20E	2.68		5.86		.457		.409	9.1	34.8	.0065	3.4	1.0	8.1	310
20F	2.78		5.80		.479		.433	8.0	36.1	.0064	3.4	1.0	7.0	270
													Avg. 8.7	Avg. 310
106	1.29	2.26		.571		.347*		4	33.2	.0066	4	0.6	3.4	130
106A	2.23	4.26		.523		.301*		5.5	57.3	.0060	4	0.6	4.9	200
106B	3.10	5.40		.573		.346*		4	79.7	.0056	4	0.5	3.5	160
108	1.53	3.20		.479		.296*		7	39.3	.0063	4	0.6	6.4	250
109-1	1.57	2.77		.567		.332*		4.5	40.4	.0063	4	0.6	3.9	160
109-2	1.33	4.26		.312		.854*		6	34.2	.0063	4	0.6	5.4	200
													Avg. 4.6	Avg. 180
99C	0.390	0.91		.428		taken as P_e/P_o		10	14.8	.0080	40	5.0	5.0	160
99D	0.698	1.69		.412				11	26.5	.0069	40	4.3	6.7	240
99E	0.844	1.93		.437				9	32.0	.0066	40	4.1	4.9	190
99F	0.995	2.37		.419				10	37.8	.0063	40	4.0	6.0	240
100	1.56	3.49		.448				9	59.2	.0060	40	3.8	5.2	220
101	0.74	1.72		.430				10	28.1	.0068	40	4.3	5.7	210
													Avg. 5.6	Avg. 220
201	1.09	4.67		.223		.800		15	188	.0049	140	2.0	13	660
202	1.32	5.18		.257		.720		17	229	.0048	140	2.0	15	780
203	1.36	6.63		.205		.845		16	234	.0048	140	2.0	14	730
													Avg. 14	Avg. 620
601	0.272		0.736		0.370		.748	8	64.7	.0058	50	0.7	7.3	310
602	0.307		0.859		0.358		.793	7	73.0	.0057	50	0.7	6.3	280
603	0.309		0.865		0.357		.810	6.5	73.6	.0057	50	0.7	5.8	250
													Avg. 6.5	Avg. 280
103	0.52	1.50		.347		taken as P_e/P_o		17	19.8	.0072	40	4.5	12.5	430
103A	1.03	2.86		.359				16	39.2	.0063	40	3.9	12.1	480
103B	1.59	4.55		.349				17	60.5	.0060	40	3.8	13.2	550
													Avg. 12.6	Avg. 490
301	1.30	7.88		.165		.70		45	224	.0048	160	2.4 +14†	28.6	1490
302	1.39	6.63		.210		.54		36	240	.0047	160	2.3 +14†	19.7	1050
													Avg. 24.2	Avg. 1270
501	0.369		1.23		0.301		.767	12	70	.0058	0	0	12	520
502	0.353		1.11		0.318		.738	14	67	.0059	0	0	14	590
													Avg. 13	Avg. 560
401	1.49	8.32		.179		.75		31	257	.0047	170	2.4	28.6	1520
402	1.31	6.65		.197		.81		23	226	.0048	170	2.5	20.5	1070
403	1.35	7.26		.186		.83		24	233	.0048	170	2.5	21.5	1120
404	1.52	6.31		.240		.59		26	262	.0047	400	5.7	20.3	1080
405	1.47	6.42		.232		.66		24	257	.0047	400	5.7	18.3	970
													Avg. 21.8	Avg. 1150

* Corrected to exit of 2-in. line.
† The +14 is from N_s in Runs 200.

linear velocity led to the conclusion that acoustic velocity existed somewhere in the system. With the linear velocity fixed, increases in mass vapor rate result in a proportional increase in pressure to accommodate the larger flow. For the 1-in. and 3-in. units acoustic velocity would occur at the inlet to separator B which is the point of lowest pressure in the small diameter vapor piping. In the case of the 2-in. unit, the critical point would be either where the 2-in. line expands to 3 in. or at the inlet to separator B.

Sonic velocity for fatty acids may be calculated from the relation (*1*)

$$c^2 = kg_c P_c v_c$$

which for an ideal gas can be expressed as

$$c^2 = kg_c \frac{RT}{MW}$$

For fatty acids k, the ratio of specific heats, is low (1.15 for acetic acid) and if isothermal flow is considered, it may be taken as 1.0. Using the relation for ideal gases, c = 426 ft./sec. for tallow acids (mole wt. 274).

Calculation of Flow Resistance. Since the change in absolute pressure through the system is large compared with the total pressure, all calculations were based upon the method of C. E. Lapple (*1*). It was assumed that the fatty acid vapor acted as a perfect gas under the test conditions of approximately 240° C. and 20 mm. Hg. abs. First, Lapple's method of calculation was checked by comparing the actual vapor flow through a portion of the system with the calculated vapor rate. The portion of the system considered had the equivalent of 26 ft. of straight 3-in. pipe and was arranged so that it was reasonable to assume that acoustic velocity existed at the downstream end (between points P_2 and P_c, Fig. 3a). Table 2 shows the good agreement obtained. In view of the small liquid to vapor volume, only the vapor volume was considered.

Accepting Lapple's method, the resistance to flow in a system can be calculated from the upstream and downstream pressures and the known mass vapor rate. These calculations are outlined in Table 3 for all the separators studied. The raw data are in Table 1; N is found from charts in the reference cited. The flow was assumed to be isothermal but, even if this were not true, k for fatty acid is low and the chart for $k = 1.0$ was presumed to be satisfactory. N is the total resistance to flow in velocity heads so it was necessary to determine Reynolds number and Fanning friction factor in order to correct for known pipe and fittings between

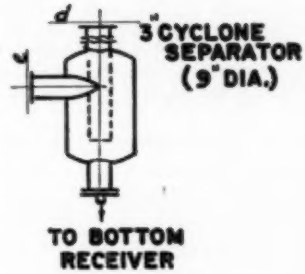


Fig. 3b. 3-in. cyclone, piping arrangement same as Fig. 3a.

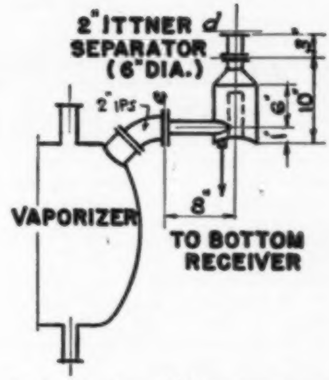


Fig. 3c. 2-in. Ittner, piping arrangement same as Fig. 3a.

the pressure taps. For Reynolds number determination the viscosity of water vapor was taken as 0.0115 cp. (*1*) but for fatty acid vapor and for glycerine vapor no figure was known, so 0.0100 cp. was assumed. The equivalent length of fittings was taken from the Crane Co. Tech. Paper No. 409.

As shown in Table 3 N_s and L_s/D, the resistance to flow by the separator, has been calculated for each unit tested. Using velocity heads (N_s), error in the assumed viscosity only affects the correction for known pipe and fittings; using equivalent number of pipe diameters (L_s/D), error in the viscosity affects the value of separator resistance directly.

TABLE 4

Separator	Vapor	Measured By		N_s	L_s/D
1-in. Ittner	Fatty Acid	Author		8.7	310
2 " Ittner	Fatty Acid	Author		4.6	190
3 " Ittner	Fatty Acid	Author		5.6	220
20 " Ittner	Glycerine	Author		6.5	280
			Avg:	6.4	250
16-in. Ittner	Water	Factory		14.	620
3-in. Cyclone	Fatty Acid	Author		12.6	490
16 " Webre	Glycerine	Author		13.0	560
			Avg:	12.8	530
16 " Webre	Water	Factory		24.2	1270
16 " Cyclone (60-in. shell)	Water	Factory		21.8	1150
			Avg:	23.0	1210

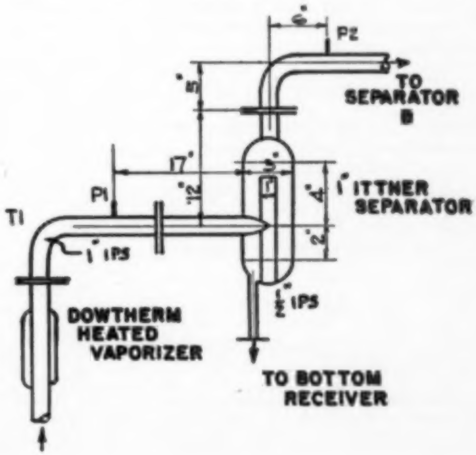


Fig. 3d. Piping arrangement for test separator—1-in. Ittner.

Flow Resistance vs. Flow Rate. Examination of the results in Table 3 (repeated in last column of Table 1) shows no definite correlation between flow resistance and throughputs (Runs 20A-20F, 106-106B, 99C-100, 103-103B). There is sufficient scatter in the data so that a relationship may exist but cannot be discerned here. Run 109-2 is similar to Runs 108 and 109-1 save that the vacuum jets were loaded to raise the static pressure in the system. As can be seen, the pressure at P_o was raised about 50% and that at P_2 about 350%. The linear velocity dropped with the rise in pressure and acoustic velocity disappeared but the flow resistance of the separator remained within the range found in the other runs.

Flow Resistance vs. Size and Type of Separator. A summary of the average flow resistance of the separators is given in Table 4. In general, there is no indication of any change in flow resistance of either Ittner- or Webre-cyclone separators with size. Variations between different size Ittner units used in fatty acid distillation as well as the variations noted for different runs on the same unit may be due to air leaks in the small systems and to small errors in manometer readings. Between different size units attempts were made to maintain dimensional similarity but there may have been some errors in fabrication and alignment of tangential inlets.

The Webre-cyclone separators differ from the Ittner design in their 180°-reversal of flow. The flow resistance caused by this change in flow pattern far exceeds that expected for a simple return bend and is probably related to the inner vortex discussed in some detail by Shepherd and Lapple (*3,4*) for cyclone dust collectors. It is interesting to note that these authors obtained a correlation for the flow resistance of cyclone dust collectors at atmospheric pressure.

$$F_{cv} = K\frac{bh}{e^2}$$

Where F_{cv} is the cyclone friction loss expressed as the number of inlet velocity heads and hence identical to N_s, bh is the inlet area, e the exit duct diameter and K is a constant equal to 16.0 for simple cyclones. For units with circular inlets of the same diameter as the exit duct,

$$F_{cv} = 16\frac{\pi}{4} = 12.6$$

This is in good agreement with the value of N_s obtained here.

Flow Resistance vs. Liquid Load. No attempt was made to explore the effect of liquid load on flow resistance. As can be seen in Table 1, the ratio of liquid to vapor as shown by the per cent overhead was essentially constant throughout all runs with a given separator. Since the vapor volume was large, the liquid volume was ignored in all the calculations used in this study.

Summary

It was shown that the pressure vs. flow calculation method of C. E. Lapple is applicable to these high velocity, high pressure drop systems. Using Lapple's method the resistance to flow of these centrifugal separators was calculated. It was found that units with tangential inlet and straight-through flow to the exit gave about half as much resistance to flow as did units incorporating a 180°-reversal similar to cyclone dust collectors (6.4 compared with 12.8 inlet velocity heads). For cyclones similar to the latter units the relation developed by Shepherd and Lapple gives 12.6 pipe diameters.

Notation

- b = width of rectangular cyclone inlet duct
- c = acoustic velocity
- e = diameter of cyclone exit duct
- f = Fanning friction factor
- g_c = conversion factor 32.17 (lb. mass.) (ft.) / (lb. force) (sec.) (sec.)
- h = height of rectangular cyclone inlet duct
- k = ratio of specific heats C_p/C_v
- v = specific volume of fluid
- D = diameter of test pipe or separator inlet
- F_{cv} = cyclone friction loss in inlet velocity heads
- K = constant
- L = length of test section in equivalent feet of straight pipe
- MW = molecular weight
- N = $4fL/D$ = friction loss in velocity heads for test pipe
- OH = overhead from distillation unit
- P = pressure, modified by subscripts
- R = gas constant/mole. 1546 ft.lb. force/lb. mole, ° F.
- T = temperature in degrees
- L/D = number of pipe diameters

Subscripts:

- o means in infinite reservoir upstream of test section
- 1 means in pipe upstream of test section
- 2 means in pipe downstream of test section
- c means at point of acoustic velocity
- k means known pipe and fittings
- s means test separator

Literature Cited

1. Lapple, C. E., *Trans. Am. Inst. Chem. Engrs.*, **39**, 385 (1943).
2. Perry, J. H. (Ed.), "Chemical Engineers' Handbook," McGraw-Hill, New York (1941).
3. Shepherd, C. B., and Lapple, C. E., *Ind. Eng. Chem.*, **31**, 972 (1939).
4. Shepherd, C. B., and Lapple, C. E., *Ind. Eng. Chem.*, **32**, 1246 (1940).
5. Webre, A. L., and Robinson, C. S., "Evaporation," The Chemical Catalog Co., New York, p. 108 (1926)

Discussion

John W. Michel (Carbide & Carbon Corp., Oak Ridge, Tenn.): Do you have any figures on the relative efficiency of the three types of separators, i.e., the entrainment separation efficiency?

E. A. Lawrence: We don't have anything in presentable form. We obviously did these studies primarily to get efficient separators and to study entrainment efficiency, but we made our measurements in terms of distillate color. We tried to get some idea of separator efficiency by seeing how much bottoms were required to give a given increment in distillate color. We found that if we added all the bottoms to the distillate we get a color which was much darker than the feed we started with. Consequently we were not sure if the bottoms we were taking out of the run-down tank were representative of the bottoms we were trying to separate in the separator itself. We tried using tracers like iron soaps and nickel soaps, dissolved in the feed stocks and made a metal analysis on the overhead. But we found we were running overhead analyses in the order of 2 or 3 p.p.m., and the inaccuracy of the method of analysis was greater than the precision we were looking for. As a matter of fact, we couldn't even get material balances though we tried very hard on that. I'm afraid I just don't have anything on separator efficiency.

R. H. Bunzl (Shell Chemical Corp., Concord, Calif.): In one of your slides you showed three different designs for separators, and the last one showed a capped center tube. I wonder in what way that capped tube aids your separation?

E. A. Lawrence: I think the capped tube is advisable. Neglecting pressure drop, I believe you'd get better efficiency with a larger central pipe which would reduce the annular space. I think when the vapor leaves the tangential inlet it tends to fan out unless it is restricted by the central duct. We did not make any runs with the central pipe removed.

(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

FRICTION AND TRANSFER COEFFICIENTS FOR SINGLE PARTICLES AND PACKED BEDS

W. E. RANZ, University of Illinois, Urbana, Illinois

A method of analysis based on properties of a single particle is developed for estimating and characterizing transfer rates and pressure drops in packed beds. Transfer rates and friction factors for spheres are related through the application of a simple model to heat- and mass-transfer rates and pressure drops in beds packed with spherical particles. Equations for estimating effective thermal conductivity and diffusivity are derived, and parametric constants relating the actual fluid velocity and the average lateral velocity to the superficial velocity, are shown to characterize the performance of a packed bed. This method of analysis reveals the mechanisms by which energy is lost and transfer occurs and appears to have application to the design and evaluation of any transfer device which is an assemblage of a large number of simply shaped interfaces arranged in an ordered or random pattern.

IT has become the practice to treat an elaborate transfer device in a qualitative and over-all manner without a serious attempt to inquire deeply into the fundamental mechanisms of transfer within an element of the apparatus large enough to be representative of the whole and small enough to allow a complete understanding of what is happening within. Such an understanding would lead to a logical choice of equipment and conditions of operation. It would aid design of new equipment and permit intelligent criticism of existing practice.

Considerable information now exists on friction factors and heat- and mass-transfer rates for fundamental shapes such as plates, disks, cylinders, and spheres. In itself this information is of little use except in the case of elementary transfer surfaces, but additively it represents a basis for an understanding of complex transfer equipment.

A case in point is that of the properties of a packed bed which should submit to an analysis based on the properties of a single particle and the configuration in which it lies. The properties of interest are pressure drop, transfer rates between particle and fluid, and lateral transfer due to fluid motion. Such an analysis is made in the work which follows. Results are unusually consistent and informative; but it is not so much the results which should be emphasized as it is the method of attack and point of view.

Modern transfer devices contain collections of simply shaped interfaces arranged in an ordered or random pattern. The method of analysis developed here appears to be suited for predicting the performance of such equipment.

Appendix containing six pages, and Figures 1-8 are on file with the American Documentation Institute (Document 3600), 1719 N Street, N.W., Washington, D. C. Copies obtainable by remitting $1.00 for microfilm or $2.40 for photoprints.

Pressure Drop in Packed Beds as Additive Property of Drag Force on Single Sphere

In analyzing the pressure drop through a packed bed it is customary to consider the bed as a system of interconnected channels (*4, 18*). A method of developing pressure-drop relationships from a model which emphasizes the individual particles has been proposed before (*3*), but the suggestion has received little attention because friction factors for single spheres are not as well understood or established as those for smooth pipes. It is interesting and profitable, however, to apply the friction factors of the present day to the earlier model.

Flow Pattern Around a Spherical Particle and Drag Forces Exerted by Fluid. The flow patterns around solid shapes show marked similarities. Much that is known about spheres is deduced from information about cylinders, and what is known about spheres is applicable to any shape effectively spherical. In general, two types of drag forces are brought to bear upon the shape, a form drag and a friction drag. Form drag is the resultant of pressure forces exerted by the fluid normal to the surface of the body, and friction drag is the resultant of tangential stresses caused by the friction of the fluid against the interface. No completely satisfactory theoretical derivation has been made of the drag forces on a solid shape or of the velocity field surrounding it; but modern developments in fluid mechanics (*10*), particularly the application of boundary layer theory, have brought notable advances in an understanding of the physical situation from at least a qualitative if not a quantitative standpoint.

Figure 1*a* is a graphical representation of the normal pressure distribution on the surface of a spherical shape at $N_{Re} < 10^5$. The resultant form drag is a major contributor to the total drag force, but unfortunately it is not amenable to a simple theoretical explanation. It is sufficient for this discussion merely to mention actual observations of the pressure distribution.

Figure 1*b* is a graphical and simplified representation of the boundary layer for a sphere where flow in the undisturbed fluid outside the boundary layer follows fairly well the pattern of potential flow. The tangential forces exerted by the fluid on the surface are directly proportional to $\partial v_\theta/\partial r$. As in the case of form drag, the reverse forces on the trailing face are not as great as the retarding forces on the forward face, and a resultant friction drag contributes to the total drag on the spherical shape.

A theoretical derivation of the total drag on a sphere is scarcely possible. Experimental values of the drag coefficient are much more convenient to record and use. The drag coefficient, C_D, can be shown to be a function of Reynolds number alone (*10*), and experimental values of the drag coefficient are recorded in these terms (*15*). A plot of $C_D N_{Re}^2$ vs. N_{Re} is shown in Figure 3.

Pressure Drop in Packed Beds as an Additive Property. Although a particle in a packed bed is surrounded by other particles, it will possess an essentially individual boundary layer. There is no continuous channel along which the fluid flows; and most of the pressure drop and transfer phenomena occur on the forward face of each individual particle, not at the points of contact with other particles. An inspection of Figure 1 will support this contention for the case of drag coefficients. Pressure forces at the equatorial belt do not contribute to the resultant form drag, and $\partial v_\theta/\partial r$ at this position is essentially zero, giving

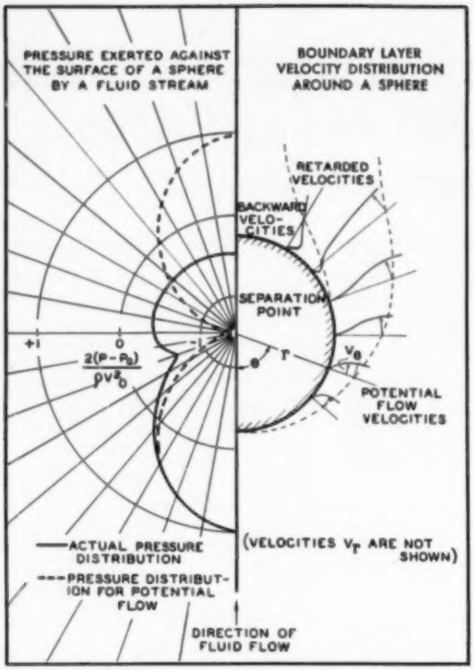


Fig. 1a. Pressure exerted against the surface of a sphere by a fluid stream. Fig. 1b. Boundary layer velocity distribution around a sphere.

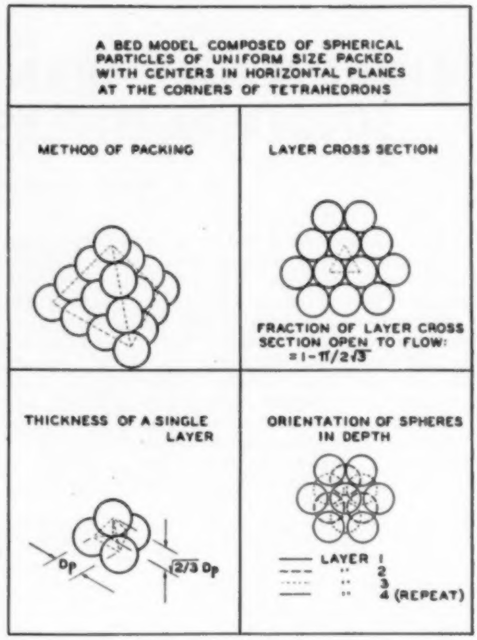


Fig. 2. A bed model.

no contribution to friction drag. It is not unreasonable, therefore, to expect that drag forces for single particles are in some way additive for a collection of particles and appear as pressure drop across a packed bed.

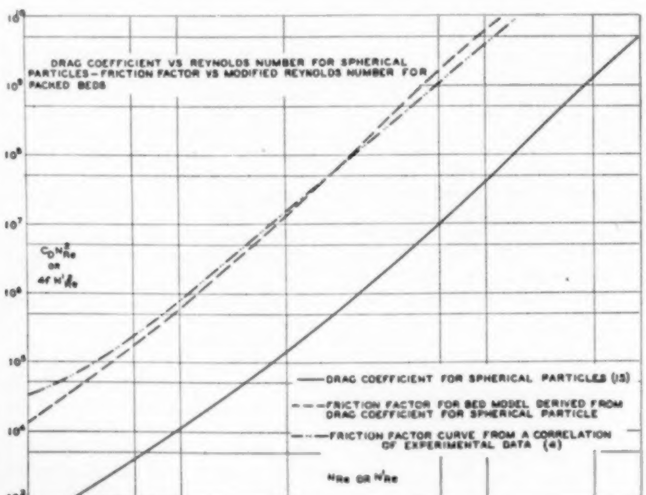


Fig. 3. Drag coefficient vs. Reynolds number for spherical particles and friction factor vs. modified Reynolds number for packed beds.

Pressure Drop in a Model Bed. If the drag force on a single particle, in terms of the experimental drag coefficient, is additive areawise across a single layer of a packed bed and depthwise through many layers, a summation of the forces on all the particles should give the pressure drop through a given depth of bed.

For example, consider a model bed composed of spherical particles of uniform size packed with their centers at the corners of tetrahedrons. Bases of the tetrahedrons lie in horizontal planes, and the particles reside in an example of closest packing. Figure 2 is a graphical representation of the arrangement which is known as the rhombohedral type of packing. Assuming the principle of additivity, the pressure drop per unit length of packing will be equal to the drag force on a single particle multiplied by the number of particles per unit volume of packed bed.

$$\frac{\Delta P}{L} = \frac{F_n}{g_c} = \frac{\rho v^2 A C_D n}{2g_c}$$

$$4f = \frac{2g_c D_p \Delta P}{\rho v_s^2 L} = D_p A n (v/v_s)^2 C_D$$

For rhombohedral packing

$$n = \sqrt{2}/D_p^3; \qquad A = \pi D_p^2/4$$

from which

$$4f = (\pi/2\sqrt{2})(v/v_s)^2 C_D = 1.111 (v/v_s)^2 C_D$$

or

$$4fN'^2_{Re} = (\pi/2\sqrt{2}) C_D N_{Re}^2 = 1.111\, C_D N_{Re}^2 \qquad (1)$$

The major difficulty in applying Equation (1) lies in the problem of determining the value of the velocity, v, to use when calculating pressure drop from C_D. Only the superficial velocity, v_o, can be obtained easily; and this velocity will be considerably smaller than the actual velocity, v, of the fluid past the particle. Some suitable relationship between v and v_o must be available, therefore, to make Equation (1) of practical application.

As an approximation for the model bed the relationship between v and v_o, for flow in a vertical direction, can be given by

$$v/v_o = 1/(1 - \pi/2\sqrt{3}) = 10.73$$

or

$$N_{Re}/N'_{Re} = 10.73 \qquad (2)$$

where it is assumed that the velocity is increased in direct proportion to the decrease in open area presented to the forward moving fluid stream by a single layer of particles. Such an approximation should not be greatly in error since each particle is positioned directly in front of a jet formed by three other particles in the preceding layer, and the velocity experienced by the particle will be to a large extent the velocity of the jet.

Graphical Representation in Which Velocity Problem Is Reduced to Simple Form. If $C_D N_{Re}^2$ is plotted against N_{Re} and $4fN'^2_{Re}$ against N'_{Re}, where N'_{Re} refers to the modified Reynolds number based on the superficial velocity, the problem of the proper velocity to use in the friction factor relationship is reduced to a simple form since the ordinate no longer contains the velocity, and the abscissa contains the velocity to the first power. Figure 3 is a plot of $C_D N_{Re}^2$ vs. N_{Re} for spherical particles. Superimposed on this plot is a curve for $4fN'^2_{Re}$ vs. N'_{Re} derived from Equations (1) and (2) and a correlation curve based on a large amount of experimental data (*4*). The agreement between the derived curve for $4fN'^2_{Re}$ and this correlation curve is remarkable in view of the many approximate relationships involved in obtaining the derived curve. In addition, the derived curve is a smooth curve following the smooth curve for drag coefficients, and the absence of a sharp break in the pressure-drop curve between so-called turbulent and viscous regions is no mystery and does not have to be explained.

Parameter for Characterizing Performance of Packed Bed in Terms of Relationship between Actual and Modified Reynolds Numbers. Since pressure drop appears to be an additive property, the relationship between v and v_o or N_{Re} and N'_{Re} can be proposed as a characteristic parameter of a packed bed. This parameter is not a simple proportionality between N_{Re} and N'_{Re} because it should be a combination of the constants of Equations (1) and (2) which displace the drag coefficient curve, $C_D N_{Re}^2$ vs. N_{Re}, in Figure 3 upward by a factor of $4fN'^2_{Re}/C_D N_{Re}^2$

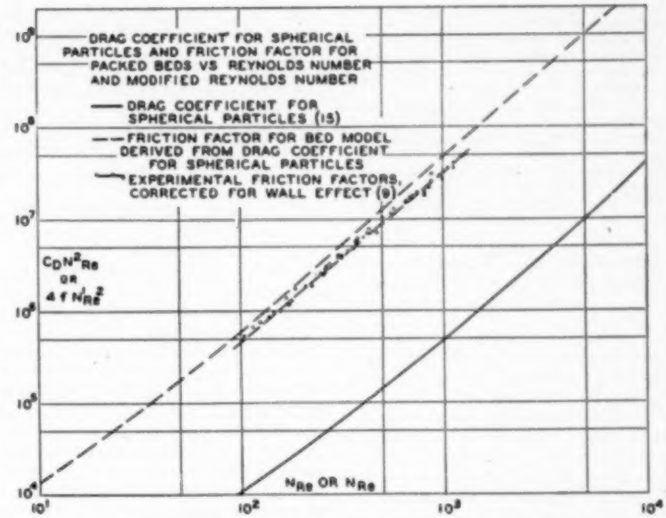
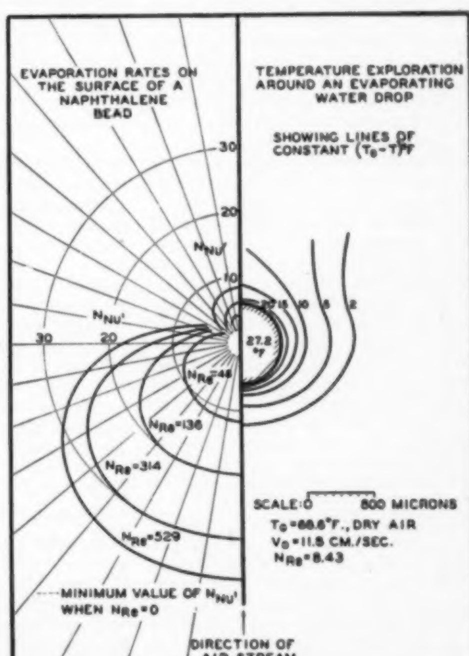


Fig. 4. Drag coefficient for spherical particles and friction factor for packed beds vs. Reynolds number and modified Reynolds number.

and to the left by a factor of N_{Re}/N'_{Re}, to become the pressure-drop curve, $4fN'^2_{Re}$ vs. N'_{Re}. However, since the constant of proportionality between $4fN'^2_{Re}$ and $C_D N_{Re}^2$ will always be near unity, the parametric constant reduces essentially to a proportionality between N_{Re} and N'_{Re}.

For example, Figure 4 shows friction factors for packed beds of spherical particles used by Gamson, Thodos, and Hougen (*9*) in making transfer measurements.



5a. 5b.

Fig. 5a. Evaporation rates on the surface of a naphthalene bead. Fig. 5b. Temperature exploration around an evaporating water drop.

Data have been corrected for the wall effect according to the computations of Furnas (*8*) so that the pressure drop will be representative of the packing alone. The average parametric constant for these beds is approximately $N_{Re}/N'_{Re} = v/v_s = 9.1$.

It is interesting to compare this parametric constant obtained from pressure-drop data with a similar parametric constant obtained from transfer data which were taken at the same time, assuming that transfer coefficients for packed beds are additive properties of the transfer coefficients for single particles.

Transfer Rates in Packed Beds As Additive Property of Transfer Rates for Simple Particle

A determination of accurate heat- and mass-transfer rates between particle and fluid in a packed bed is a difficult problem, and an adequate interpretation of the data is exceedingly complicated. Recent work on transfer rates for single particles makes it possible to interpret rates in packed beds as additive properties of the rates for single particles, and such an interpretation goes a long way in providing a better understanding of the operation of such a transfer device.

Qualitative Picture of Heat- and Mass-Transfer Rate Distribution over Surface of Spherical Particle. Figure 5*a* shows the distribution of mass-transfer rates around a sphere. Data are from Froessling (*7*) and concern the sublimation of small naphthalene beads in air. Figure 5*b* shows the temperature field around an evaporating water drop (*19*). The rate pattern and the relative spacing of the isotherms can be explained in terms of the velocity field of the boundary layer shown partially in Figure 1*b*. On the forward face high negative radial velocities and high tangential velocities adjacent to the surface contribute most to an increase in the potential gradients of temperature and concentration; heat- and mass-transfer rates are at a maximum, and the temperature isotherms are close together. As the separation point is approached, transfer rates decrease along with a decrease in tangential and negative radial velocities; and at the separation point, where these velocities are aiding least in the convection mechanism of transfer, the rate is at a minimum. On the trailing face transfer rates increase again to a lower maximum which is commensurate with the magnitude of the backward velocities.

Again, as in the case of pressure drop, a major contribution to the total transfer occurs on the forward and rearward faces of the particle. In a packed bed there is no continuous flow through channels but a passage of fluid from the boundary layer of one particle to the boundary layer of another particle, and most of the transfer occurs on the surface areas facing the oncoming fluid stream, not at points of flow restriction.

Transfer Correlations for Spherical Particles. A mathematical statement of the boundary layer problem shows that transfer rates for spheres can be given in a universal functional form as

$$N_{Nu} = N_{Nu}(N_{Re}, N_{Re}N_{Pr}) = N_{Nu'}(N_{Re}, N_{Re}N_{Pr}) \qquad (3)$$

$$N_{Nu'} = N_{Nu'}(N_{Re}, N_{Re}N_{Sc}x_f) = N_{Nu}(N_{Re}, N_{Re}N_{Sc}x_f) \qquad (4)$$

where N_{Pr} for heat transfer is equivalent to $N_{Sc}x_f$ for mass transfer. To obtain empirical correlations, experimental data are plotted customarily in either of two forms, N_{Nu} vs. $N_{Pr}{}^{1/3}N_{Re}$ and $N_{Nu'}$ vs. $N_{Sc}{}^{1/3}N_{Re}$ or as $j_H(= N_{Nu}/N_{Re} N_{Pr}{}^{1/3})$ vs. N_{Re} and $j_D(= N_{Nu'}/N_{Re} N_{Sc}{}^{1/3})$ vs. N_{Re}. For the purpose of demonstrating the additive characteristics of transfer rates, the first method of plotting proves to be the simpler since the ordinate does not contain the velocity and the abscissa contains the velocity to the first power.

Figure 6 shows a plot of a variety of transfer data (*7, 14, 16, 19*) for single spheres over a wide range of Reynolds numbers ($1 < N_{Re} < 70{,}000$) and Prandtl and Schmidt numbers ($0.6 < N_{Pr}$ or $N_{Sc} < 400$). A simple correlation equation in a form originally suggested by Froessling (*7*) can be written which fits the data fairly well up to a value of N_{Re} of 10^4 and for values of N_{Pr} or N_{Sc} between 0.6 and 400. This correlation form is

$$N = 2.0 + 0.60\ \xi^{1/3} N_{Re}{}^{1/2} \qquad (5)$$

where $N = N_{Nu}$ and $\xi = N_{Pr}$ for heat transfer and $N = N_{Nu'}$ and $\xi = N_{Sc}$ (perhaps more exactly $N_{Sc}x_f$) for mass transfer. It is interesting to note that such a correlation form also describes heat and mass transfer from cylinders normal to a fluid stream. In this case the constant is 0.55 instead of 0.60 and the apparent minimum value of N is $1/\pi$ at $N_{Re} = 0$.

Equation (5) is a useful equation. It is a simple relationship and has wide application to chemical engineering problems. If accurate values of the physical constants are available, it will give a good estimate of transfer rates to be expected in situations involving spherical interfaces.

Transfer Rates in Model Bed. To estimate transfer rates in the model bed of Figure 2 the particles can be assumed to act essentially as free particles experiencing an actual velocity greater than the superficial velocity by the factor given in Equation (2). This is in consequence of the fact that each particle of the model bed is located in front of a jet formed by three particles preceding it and the fact that most of the transfer occurs at the point where the jet impinges upon the forward face of the particle. A derived curve for transfer rates in a model bed in which N_{Re} is taken as $10.73N'_{Re}$ is shown in Figure 6 along with experimental data (*9*). The parallelism of the various transfer curves is obvious.

Parametric Constant in Terms of Transfer Rates. If the relationship between the actual and superficial Reynolds numbers is a parametric constant of a packed bed, the relative displacement of the data of Gamson, Thodos, and Hougen (*9*) for beds packed with spherical particles from the data for single spheres should give an average parametric constant for the bed upon which they performed their experiments. From Figure 6 this constant is found on the average to be 9.1, in exact agreement with the same parametric constant determined from pressure-drop measurements and in accord with the calculated parametric constant for a model bed. It is interesting to note that with one pressure-drop measurement and Equation (5) one should be able to estimate to a good approximation the transfer rates for a bed packed with spherical particles.

The ratio between actual and superficial Reynolds numbers appears to be a characteristic constant of a given packed bed and is of the order 10^{+1}. It can be determined simply by pressure-drop measurements, and it has definite physical significance. Even though these results are limited to spherical particles, the method of interpretation is not so limited and can be applied qualitatively to an evaluation of the usefulness and efficiency of collections or arrangements of any other shape of transfer interface.

Such a plot as Figure 6 is limited to a range of N_{Pr} and N_{Sc}. Voluminous data now available on transfer rates in packed beds can be interpreted directly in terms of Figure 6 if the values of all the variables lie within the specified range. The method of analysis can be applied, however, to a wider range of variables, such as in the case of the data of McCune and Wilhelm (*17*), where $N_{Sc} > 1000$ and where both the data for single spheres and for packed beds are displaced to the right of the curves shown on Figure 6, but where the ratio between N_{Re} and N'_{Re} is still of the same order of magnitude.

Effective Thermal Conductivity and Diffusivity in Packed Beds

A full understanding of transport phenomena in packed beds requires

knowledge of effective transport properties which can be considered similar in mathematical form and use to intermolecular transport properties but different in mechanism of transfer. Waddams (22) and Schumann and Voss (20) have presented correlations of experimental heat conductivities for packed beds in which the fluid is at rest. Except for extraordinary cases in which the particles possess relatively large conductivities, the order of magnitude of the effective conductivities is the same as that of molecular conductivities in the fluid phase. Recent works of Hall and Smith (11), Coberly and Marshall (5), Hougen and Piret (13), Bernard and Wilhelm (2), and Singer and Wilhelm (21), reveal values of effective conductivities and diffusivities so large in comparison with values for the fluid at rest that gross transfer of fluid masses must have been involved as well as transfer by simple convection, conduction, and diffusion.

If lateral transfer is treated as a separate phenomenon, effective transport properties can be written as

$$k_{\perp} = k_{\parallel} + k_m \tag{6}$$

$$D_{\perp} = D_{\parallel} + D_m \tag{7}$$

where subscript $\perp$ refers to the value of the transport property in a direction perpendicular to the average direction of fluid flow, subscript $\parallel$ refers to the value of the property parallel to flow, and subscript m refers to the value of the property caused by lateral mixing. Immediately $k_{\parallel}$ and $D_{\parallel}$ can be dismissed as being approximately equal to the same properties for packed beds with zero fluid velocity. Their order of magnitude and order of importance can be estimated by assuming them to have the same value as the molecular coefficients in the fluid alone.

Mechanism of Lateral Transfer. At finite mass velocities, lateral transfer is caused chiefly by a mechanical mixing or riffling through channels which are not parallel to the average direction of flow. The major contribution to effective conductivity and diffusivity, that due to lateral mixing, can be estimated by considering the bed to be composed of interconnected cells whose dimensions and spacings are determined by the size and shape of the particles and the method of packing. For a unit volume of this bed, mass velocity ρv_o of fluid is entering the top and leaving the bottom, but at the same time a lateral mass velocity $a\rho v_o$ is occurring to the right and to the left (or in any lateral direction) through randomly directed channels which act as one-way passages between the openings in the bed. This lateral mass velocity is moving through each of N-planes which at any level in the unit volume can be interposed between the cells or openings whose centers are on the average $1/N$ distance apart. The temperature (or concentration) changes from T_o to T_N (or C_{Ao} to C_{AN}) through N distinct changes. The algebraic sum of heat (or mass) transferred laterally across each plane is given by

$$\begin{aligned} q_{am} &= a\rho v_o C_p(T_o - T_1) = \ldots \\ &= a\rho v_o C_p(T_{n-1} - T_n) = \ldots \\ &= a\rho v_o C_p(T_{N-1} - T_N) \end{aligned}$$

$$\begin{aligned} r_{Aom} &= a v_o(C_{Ao} - C_{A1}) = \ldots \\ &= a v_o(C_{A(n-1)} - C_{An}) = \ldots \\ &= a v_o(C_{A(N-1)} - C_{AN}) \end{aligned}$$

Adding the N-equations

$$\begin{aligned} N q_{am} &= \sum_{0}^{N} a\rho v_o C_p(T_{n-1} - T_n) \\ &= a\rho v_o C_p(T_o - T_N) \end{aligned}$$

$$\begin{aligned} N r_{Aom} &= \sum_{0}^{N} a v_o(C_{A(n-1)} - C_{An}) \\ &= a v_o(C_{Ao} - C_{AN}) \end{aligned}$$

from which

$$k_m = a\rho v_o C_p/N$$

$$D_m = a v_o/N$$

Since N is inversely proportional to D_p for any uniform packing,

$$k_m = a'\rho v_o C_p D_p \tag{8}$$

$$D_m = a' v_o D_p \tag{9}$$

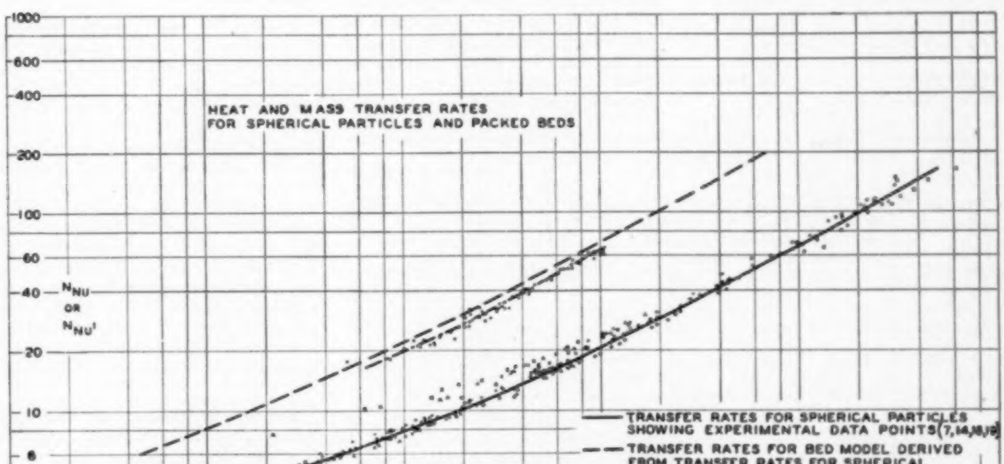


Fig. 6. Heat- and mass-transfer rates for spherical particles and packed beds.

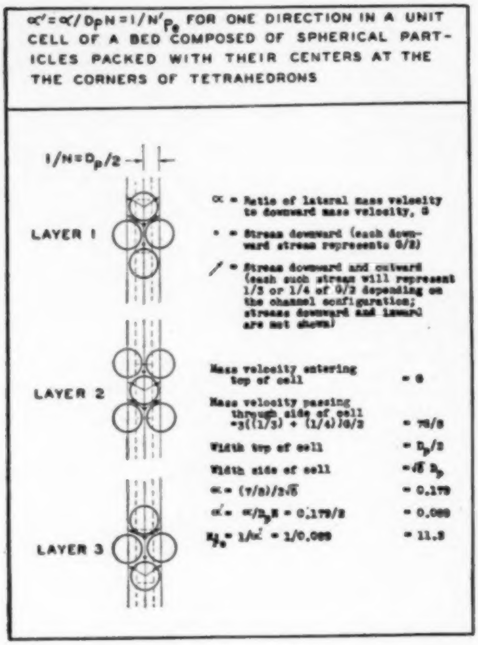


Fig. 7. $\alpha' = \alpha/D_pN = 1/N'_{Pe}$ for one direction in a unit cell of a bed model.

N represents the average number of cells or openings per unit lateral distance in the bed, and α is a fraction which, multiplied by ρv_o, represents a mass velocity moving laterally through a unit vertical cross section. By definition

$$\alpha' = \alpha/D_pN = 1/N'_{Pe} \qquad (10)$$

where N'_{Pe} is an effective modified Peclet number.

Equations (8) and (9) would result from simple dimensional analysis, but the derivation given above assigns physical meaning to the constant of proportionality. These equations predict that effective conductivities and diffusivities are, in general, proportional to the mass velocity and the size of the packing and that α' or N'_{Pe} is relatively unaffected by changes in the modified Reynolds number.

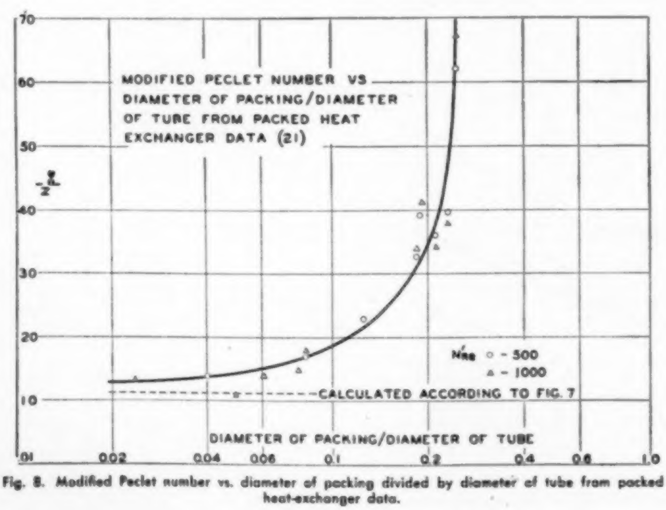


Fig. 8. Modified Peclet number vs. diameter of packing divided by diameter of tube from packed heat-exchanger data.

Parameter for Characterizing Lateral Transport Properties of a Packed Bed. $\alpha' = 1/N'_{Pe}$ is a convenient parameter for characterizing the performance of a packed bed and is a measure of the ability of the bed to transfer heat and mass in a lateral direction. Experimental values of this parameter are now available. Coberly and Marshall (*5*) obtained an α' of approximately 0.13 from data on $k_\perp$ as an average for cylindrical and spherical packings. Data of Bernard and Wilhelm (*2*) on values of $D_\perp$ show α' to be of the order of 0.08 for beds packed with spherical particles and α' of the order of 0.11 for beds packed with cylindrical particles. Singer and Wilhelm (*21*) report $\alpha' = 1/N'_{Pe}$ of a similar magnitude from data on $k_\perp$ and $D_\perp$.

Since α' is dependent on the configuration of the packing as well as the particle size and shape, it can be estimated only for unknown beds where direct measurements have not been made. A method of packing which gives well-defined channels in the direction of flow will show abnormally low α', but for ordinary packings α' of the order of 10^{-1} (or N'_{Pe} of the order of 10) is to be expected. If it becomes necessary to know α' accurately for a given bed, an experimental procedure, similar to that used by Bernard and Wilhelm (*2*) in which liquid with a trace material is forced through a sample volume of the packing, should give an α' applicable to any other fluid used with the same packed bed.

Lateral Transfer for Bed Model. In principle α' can be calculated for particles of uniform geometrical shape packed in a definite manner. For example, with the assumption that flow is completely channeled (i.e., flow in any distinct channel is in one direction) and the bed is of infinite extent, the bed model shown in Figure 7 would have an α' of 0.089. The remarkable agreement with experimental values of α' for beds composed of spherical particles is fortuitous. However, the numerical result gives strong support to the primary mechanism of lateral transfer as it is postulated here and, being a conservative value, can be recommended for use in the absence of experimental information.

Diffusion by Displacement and Wall Effect. Effective conductivities and diffusivities are examples of diffusion by finite displacements of fluid elements. They are examples of controlled displacements where the configuration of the fluid channels forms a pattern for movement. They are not examples of random displacements in the same sense as eddy diffusion which is restricted by the walls of a cell or channel, but they

can be examples of random displacement in the sense that the channels are randomly directed.

Baron (*1*) derived Equations (8) and (9) by estimating the mean square displacement of fluid in a lateral direction during a given time in its vertical motion, the diffusivity in terms of this mean square displacement being given by Einstein's statistical Equation (6),

$$D_m = \overline{\Delta_x^2}/2\Delta t \qquad (11)$$

where

$\overline{\Delta_x^2}$ = mean square displacement of an element of fluid in a lateral direction during time period Δt

Δt = contact time during which $\overline{\Delta_x^2}$ is measured

If Δt is taken as the superficial time required for an element of fluid to pass one layer of packing, i.e., Δt is approximately equal to D_p/v_o, $\overline{\Delta_x^2}$ can be roughly estimated as being equal to $(D_p/2)^2$. Under these conditions D_m will be of the order of $(1/8)v_oD_p$ or α' will be of the order of 1/8. Such a derivation is theoretically equivalent to the one given previously if $\overline{\Delta_x^2}$ and Δt are properly interpreted, and the accompanying analysis leads to the same conclusions concerning the nature and mechanism of this type of transfer.

Equation (11) is a convenient means for pointing out the effect of the wall of the containing vessel since displacements near the wall, in the direction of the wall, are restricted and the rate of transfer is decreased. Figure 8 from the work of Singer and Wilhelm (*21*) shows the effect of the wall when the ratio of particle diameter to packed tube diameter becomes large. In this particular case the experimental points have been obtained from heat transfer in packed tubes, and they indicate that transfer rates at the wall must be estimated from wall coefficients which are of the same order of magnitude as the wall coefficients for turbulent flow in open tubes. Coberly and Marshall (*5*) have made a preliminary attempt to estimate the effect of the wall in terms of a wall coefficient, but experimental information is insufficient to give a reliable correlation. For a completely satisfactory interpretation of lateral transfer of heat (and mass if mass transfer occurs through the wall) such a correlation is necessary.

Notation

A = area projected by particle against fluid stream

C_A = concentration of diffusing component A

$\Delta C_A = C_{Ao} - C_{Ai}$

$C_D = 2F/\rho v^2 A$ = drag coefficient

C_p = specific heat of fluid

D = apparent diffusion coefficient

D_{AM} = mean diffusion coefficient for diffusing component A

D_p = particle diameter

F = force exerted on particle by fluid stream

$f = g_c D_p \Delta P / 2\rho v_o^2 L$ = friction factor

g_c = dimensional conversion constant

$h_a = q_{ai}/\Delta T$ = coefficient for heat transfer = heat transfer rate per unit area of interface per unit temperature difference across limits of transfer path (heat transferred by conduction and convection)

k = thermal conductivity of fluid

$k_G = r_{Aai}/\Delta C_A$ = coefficient for mass transfer = mass transfer rate per unit area of interface per unit concentration difference across the limits of transfer path

L = depth of packed bed

$N_{Nu} = h_c D_p / k$ = Nusselt number for heat transfer

$N_{Nu'} = k_G D_p x_f / D_{AM}$ = mass-transter number analogous to N_{Nu} for heat transfer

$N_{Pe} = N_{Re} N_{Pr}$ = Peclet number for heat transfer

$= N_{Re} N_{Sc}$ = Peclet number for mass transfer

N'_{Pe} = modified Peclet number where $v = v_o$, the superficial velocity of the fluid

$N_{Pr} = C_p \mu / k$ = Prandtl number

$N_{Re} = D_p \rho v / \mu$ = Reynolds number

N'_{Re} = modified Reynolds number where $v = v_o$, the superficial velocity of fluid

$N_{Sc} = \mu / \rho D_{AM}$ = Schmidt number

n = number of particles per unit volume of packed bed

P = pressure

ΔP = difference in pressure over depth L

q = heat-transfer rate

r = mass-transfer rate

T = absolute temperature

$\Delta T = T_o - T_i$

v = velocity of fluid relative to particle

v_o = superficial velocity of fluid

x_f = concentration factor = average of $(1 - x_A)$ over transfer path where x_A is the mole fraction of component A and x_f is average mole fraction of nondiffusing components

$\alpha' = 1/N'_{Pe}$

μ = absolute viscosity of fluid

ρ = density of fluid

SUBSCRIPTS:

a denotes a measure of quantity per unit cross-section area perpendicular to direction of transfer

ai denotes a measure of quantity per unit of interfacial area

o denotes value of variable, T, C_A, or v, in undisturbed fluid stream

i denotes value of variable, T or C_A, in fluid adjacent to interface

$\perp$ denotes value of an apparent transport property in a direction perpendicular to average direction of flow

$\|$ denotes value of an apparent transport property in a direction parallel to average direction of flow

m denotes value of an apparent transport property caused by lateral mixing

Literature Cited

1. Baron, T., *Chem. Eng. Progress*, **48**, No. 3, 118 (1952).
2. Bernard, R. A., and Wilhelm, R. H., *Chem. Eng. Progress*, **46**, No. 5, 233 (1950).
3. Burke, S. P., and Plummer, W. B., *Ind. Eng. Chem.*, **20**, 1196 (1928).
4. Chilton, T. H., and Colburn, A. P., *Trans. Am. Inst. Chem. Engrs.*, **26**, 178 (1931).
5. Coberly, C. A., and Marshall, W. R., Jr., *Chem. Eng. Progress*, **47**, No. 3, 141 (1951).
6. Einstein, A., *Ann. Physik*, **17**, 549 (1905); **19**, 371 (1906).
7. Froessling, N., *Gerlands Beitr. Geophys.*, **52**, 170 (1938).
8. Furnas, C. C., *U. S. Bur. Mines Bull.*, **307** (1929).
9. Gamson, B. W., Thodos, G., and Hougen, O. A., *Trans. Am. Inst. Chem. Engrs.*, **39**, 1 (1943).
10. Goldstein, S., "Modern Developments in Fluid Mechanics," Oxford University Press (1938).
11. Hall, R. E., and Smith, J. M., *Chem. Eng. Progress*, **45**, No. 7, 459 (1949).
12. Hirschfelder, J. O., Bird, R. B., and Spotz, E. L., *Trans. Am. Soc. Mech. Engrs.*, **71**, 921 (1949).
13. Hougen, J. O., and Piret, E. L., *Chem. Eng. Progress*, **47**, No. 6, 295 (1951).
14. Kramers, H., *Physics*, **12**, 61 (1946).
15. Lapple, C. E., and Shepherd, C. B., *Ind. Eng. Chem.*, **32**, 605 (1940).
16. Maisel, D. S., and Sherwood, T. K., *Chem. Eng. Progress*, **46**, No. 3, 131 (1950).
17. McCune, L. K., and Wilhelm, R. H., *Ind. Eng. Chem.*, **41**, 1124 (1949).
18. Oman, A. O., and Watson, K. M., *Natl. Petroleum News, Tech. Sec.*, **36**, R795 (1944).
19. Ranz, W. E., and Marshall, W. R., Jr., *Chem. Eng. Progress*, **48**, No. 3, 141 (1952).
20. Schumann, T. E. W., and Voss, V., *Fuel*, **13**, 249 (1934).
21. Singer, E., and Wilhelm, R. H., *Chem. Eng. Progress*, **46**, No. 7, 343 (1950).
22. Waddams, A. L., *Chemistry & Industry*, 206 (1944).
23. Winklemann, A., *Ann. Physik.*, **22**, 152 (1884); **33**, 445 (1888); **36**, 93 (1889).

MULTICOMPONENT DISTILLATION

III—*Equations in Product Form and Simplified Application*

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Generalized algebraic equations, applicable to theoretical-plate multicomponent distillations in which the volatility ratios and the molal vapor and liquid flows remain constant within each section of the column, are shown in summation form and in the equivalent product form. For a doublet separation in which the relative volatilities and the molal liquid and vapor flows remain constant throughout the column, an analytical solution giving optimum feed plate location is presented in Equations (7), (8), and (11). This solution is further simplified by an approximation which amounts to the reduction of the system to an equivalent binary. The plate requirement, as calculated by use of the resulting equations, Equations (12) and (13), is indicated by examples to be of good accuracy unless the keys make up only a small fraction of the column feed. The time required for a calculation by the approximate method is much less than that required for use of the equations presented previously (*6, 7*).

PREVIOUS papers (*6, 7*) have shown algebraic equations applying to theoretical-plate multicomponent distillations in which the volatility ratios and the molal vapor and liquid flows within each section of the column are constant. The equation for Dx_D/Bx_B of any component was in the form of a ratio of sums of exponential terms. The purpose of the present paper is to present a simpler manner of representing this equation for any thermal condition of the column feed, and to restate the latter equation in the form of a ratio of products of factors. It will be shown that the product form of the equations leads to considerable simplification in the numerical solution of certain types of distillation problems when the volatility ratios are constant throughout the column. A solution obtained in this way is exact at minimum reflux and is of a high order of accuracy when the reflux is not far above the minimum, as is ordinarily the case for the economically optimum reflux. A still simpler approximation is also developed and is shown to be of adequate accuracy for ordinary separations. It gives the number of rectifying and stripping trays separately; it is exact for total plates at total reflux, and (for the examples investigated) within a few per cent at a reflux ratio 25% above the minimum. This approximation, obtained mathematically, amounts to replacing the actual feed to the column by an equivalent binary. The latter is approximately, but not exactly, the same as that employed by Hengstebeck (*4*), who obtained plate numbers graphically.

In general, the algebraic approach has resulted in the derivation of equations representing the steady-state behavior of theoretical-plate distillation columns. These equations can be used to develop suitable calculational procedures and to show logically the effects of changes in operating conditions on the performance of such columns. The work to date deals mainly with the derivation of the general equations and the development of suitable calculational procedures. The first paper (*6*) in this series showed how the results of carrying out repeated plate-to-plate calculations could be represented algebraically. Equations were not well suited for computational use because of their complexity. Harbert and Underwood (*3, 11*) arrived at the same equations; Harbert's approach was empirical while that of Underwood was algebraic, but using a method of derivation differing from (*6*). In the second paper of this series (*7*), a calculational method applicable to doublet separations was given. This method consisted of setting up and solving simultaneously a set of linear algebraic equations. This solution was carried out numerically. A similar solution, using determinants, has been obtained by Alder and Hanson (*1*). The present paper shows in effect that when the volatility ratios (α values) are constant throughout the column, the method of the second paper can be greatly shortened. This is because an algebraic equation representing the *solution* of the simultaneous equations can be used. In addition, this method gives an analytical solution for optimum feed plate location.

In order to direct attention to the results, the details of the derivations given in the original manuscript upon which this paper is based will not be given here.

In the interest of uniformity, and because the quantities called by Underwood the ϕ and ψ values are especially convenient for minimum reflux calculations, a system of nomenclature analogous to that of Underwood (although differing somewhat) will be used. All flows employed are based on one mole of feed.

The distillation equations of the first paper (*6*) are given in the new Notation in Table *A-1* of the Appendix.

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Summation Type Equations for Any Thermal Condition of Feed

As can be seen from Table *A-1* (Appendix), the separation ratio expression, Equation (*A*-14), is simpler for boiling point liquid feed ($V_f = 0$) than for a partially vaporized feed. The first step in the derivations is to express Equation (*A*-14) in a manner which is similar for all feed conditions. The new expression is

$$\frac{Dx_{Di}}{Bx_{Bi}} = -\frac{\displaystyle\sum_{j=1}^{c} \frac{S'_j}{1 - \dfrac{\phi_{sj}}{a_{si}}}}{\displaystyle\sum_{j=1}^{c} \frac{s'_j}{1 - \dfrac{\phi_{rj}}{a_{ri}}}} \tag{1}$$

This equation can be used for the calculation of doublet separations, in a manner analogous to that proposed previously (*7*) for boiling point liquid feeds. It is applicable when the liquid and vapor flow ratio and the volatility ratios are constant within a section of the column, but the values in the rectifying section may differ from those in the stripping section.

Equations in Product Form. In the remainder of this paper, it will be assumed that each a is constant throughout the column. The a value for component i will be labelled $a_i (a_{ri} = a_{si} = a_i)$.

The calculational formulas given here involve numbers called the r_j's, which are defined in terms of equations obtained by generalizing the numerator and denominator of Equation (1) separately. These defining equations are

$$\sum_{i=1}^{c} \frac{s'_i}{1 - \dfrac{\phi_{ri}}{r_j}} = 0 \tag{2}$$

$$\sum_{i=1}^{c} \frac{S'_i}{1 - \dfrac{\phi_{si}}{r_j}} = 0 \tag{3}$$

That is, the r_j's are the roots of these equations. These equations would be of little use if the appropriate numerical values of the r's could not be determined. Actually these values are readily fixed at minimum reflux. It can be shown that at this reflux

for

$$2 \leqslant j \leqslant h \quad ; \quad r_j = \phi_{sj-1} \tag{4}$$

$$h+1 \leqslant j \leqslant l \quad ; \quad r_j = \phi_{rj} = \phi_{sj-1} \tag{5}$$

$$l+1 \leqslant j \leqslant l \quad ; \quad r_j = \phi_{rj} \tag{6}$$

If the column is operating with a reflux above minimum, but the components lighter and heavier than the keys (the "outside components") are well separated by the distillation, Equations (4) and (6) still hold, although Equation (5) does not. In the equations to follow, the substitutions corresponding to Equations (4) and (6) have been made. These substitutions have been used in solving several numerical examples, reported below, at 1.25 times minimum reflux, and one example (number 1) at 5.33 times minimum reflux. In each case the agreement with the results of accurate calculations was good. For large refluxes, approaching total, the choice of r values does not affect the total plate requirement appreciably. At total reflux, the total plate requirement is independent of the choice of r values. Therefore, the substitutions corresponding to Equations (4) and (6) are believed to be adequate for doublet separations throughout the entire reflux range from minimum to total.

Doublet Separations. A doublet separation is one for which the keys are adjacent, and all outside components are well separated by the distillation. For this case

$$\left(\frac{\phi_{rl}}{\phi_{rh}}\right)^N = P_r \beta_r \frac{r_l - \phi_{rh}}{\phi_{rl} - r_l} \tag{7}$$

and

$$\left(\frac{\phi_{sl}}{\phi_{sh}}\right)^{M+1} = P_s \beta_s \frac{\phi_{sl} - r_l}{r_l - \phi_{sh}} \tag{8}$$

where

$$\beta_r = \frac{g_{rl}\phi_{rh}(\phi_{rl} - a_h)(a_l - \phi_{rl})}{g_{rh}\phi_{rl}(a_h - \phi_{rh})(a_l - \phi_{rh})} \tag{9}$$

$$\beta_s = \frac{g_{sh}\phi_{sl}(\phi_{sh} - a_h)(a_l - \phi_{sh})}{g_{sl}\phi_{sh}(\phi_{sl} - a_l)(\phi_{sl} - a_h)} \tag{10}$$

As will be shown both P_r and P_s (*see* Notation) can, in many cases, be set equal to unity with satisfactory accuracy.

The value of r_l to be used in Equations (7) and (8) lies between ϕ_{sh} and ϕ_{rl}; that is $\phi_{sh} < r_l < \phi_{rl}$. Within these limits the value of r_l can be assigned arbitrarily, and for each assigned value there is a corresponding N and M. In other words, the value of r_l chosen determines the feed plate location.

Underwood has published (*12*) the complicated relation which could be obtained by eliminating r_l from Equations (7) and (8), but has not given the separate equations. This relation was given for the special case of Example No. 4, Table 1. The derivation was by direct but tedious algebraic elimination from the original summation formulas. The relation was not used for calculational purposes.

Optimum Feed Plate Location for Doublet Separations

The optimum feed plate location may be found either graphically or alge-

TABLE 1.—STATEMENT OF EXAMPLES

Relative Volatilities, Separation Specifications, and Feed Compositions for Examples 1-7

Comp. No.	Rel. Vol. a	Examples 1–7 $\frac{Dx_D}{Bx_B}$	Examples 1–3 X_f	Example 5 X_f	Example 6 X_f	Example 7 X_f
1	0.25	......	0.100	0.05	0.50	0.26
2	0.50	0.050	0.225	0.15	0.15	0.05
3	1.00	20.005	0.450	0.30	0.30	0.10
4	2.00	......	0.225	0.50	0.05	0.59

Example No.	Statement and Specifications	Feed Condition	Reflux Ratio
1	above	Boiling Point Liquid	5 : 1
2	above	Boiling Point Liquid	1.25 × min.
3	above	60% Vaporized	1.25 × min.
5	above	Boiling Point Liquid	1.25 × min.
6	above	Boiling Point Liquid	1.25 × min.
7	above	Boiling Point Liquid	1.25 × min.

Example No. 4, from Underwood (*12*)

Comp. No.	Rel. Vol. a	X_f	$\frac{Dx_D}{Bx_B}$
1	1	0.1	
2	2	0.2	
3	3	0.2	0.025641
4	4	0.2	39.000
5	5	0.3	

Feed Condition: Boiling Point Liquid.
Reflux Ratio: 5 : 1.

TABLE 2.—PLATE REQUIREMENTS CALCULATED BY VARIOUS ALGEBRAIC METHODS *

Example No.	Method	N	M	$N+M$
1	Algebraic Equations in Original Form (6)	4.30	4.72	9.02
	s, S, Equations	4.36	4.59	8.95
	r Equations	4.29	4.66	8.95
2	s, S, Equations	9.00	8.26	17.26
	r Equations	9.15	8.11	17.26
4	Underwood Equations	19.0	19.1	38.1
	r Equations	18.96	19.13	39.09

* In this and the following tables, plate requirements are for the sake of comparison shown to more figures than would be justified in any actual case.

braically. In either case the method is to find the value of r_l that makes $N+M$ a minimum. The algebraic determination is made by differentiating Equations (7) and (8), and setting $dM/dN = -1$. The following equation in r_l is thus obtained.

$$\left(\log\frac{\phi_{sl}}{\phi_{sh}}\right)\frac{(\phi_{sl}-r_l)(r_l-\phi_{sh})}{(\phi_{sl}-\phi_{sh})} = \left(\log\frac{\phi_{rl}}{\phi_{rh}}\right)\frac{(r_l-\phi_{rh})(\phi_{rl}-r_l)}{(\phi_{rl}-\phi_{rh})} \tag{11}$$

This is an ordinary quadratic equation, readily solved for r_l after substituting the numerical values of the ϕ's. Substituting the value of r_l given by Equation (11) in Equations (7) and (8) gives N and M for optimum feed plate location.

When the approximation $P_r = P_s = 1$ is made, the plate requirement can be obtained with the knowledge of only four roots: ϕ_{rh}, ϕ_{rl}, ϕ_{sh}, and ϕ_{sl}.

It has been found that for the examples investigated the value of r_l corresponding to optimum feed plate location is given with sufficient accuracy by the equation

$$r_l = \phi_{sh} + (\phi_{rl}-\phi_{sh})\frac{\log\dfrac{\phi_{rl}}{\phi_{rh}}}{\log\dfrac{\phi_{sl}}{\phi_{rh}}}$$

For the sake of simplicity, plate numbers calculated from this value of r_l are, however, not shown in the tables.

Calculation of Plate Requirements for Doublet Separations

Upon setting P_r and $P_s = 1$, the equations for N and M are

$$N^* = \frac{\log \beta_r \dfrac{(r_l-\phi_{rh})}{(\phi_{rl}-r_l)}}{\log\dfrac{\phi_{rl}}{\phi_{rh}}} \tag{12}$$

$$M^*+1 = \frac{\log \beta_s \dfrac{(\phi_{sl}-r_l)}{(r_l-\phi_{sh})}}{\log\dfrac{\phi_{sl}}{\phi_{sh}}} \tag{13}$$

where N^* and M^* are the approximate N and M given by these equations, and corresponding to $P_r = P_s = 1$.

The procedure recommended for the calculation of plate requirements for constant —α doublet separations is as follows:

1. Calculate ϕ_{rh}, ϕ_{rl}, ϕ_{sh} and ϕ_{sl} by trial from the equations $\Omega_r(\phi_r) = 0$ and $\Omega_s(\phi_s) = 0$. To obtain these values with a minimum of effort, either the method of Scheibel (8) or that of Newton (9) may be employed. Application of the latter method is shown in Table 3.
2. Evaluate β_r, β_s, and (if desired) r_l for the optimum feed plate location.
3. Substitute the indicated values in Equations (12) and (13), obtaining N^* and M^*.

Comparison with Hengstebeck's Method. Hengstebeck (4) assumed, for calculational purposes, that throughout the rectifying section of a column the components lighter than the keys were present at constant compositions, and that the components heavier than the keys were absent. For the stripping section, these assumptions were reversed. The liquid and vapor flows of the keys were calculated on this basis, and the plate requirements then determined by means of a McCabe Thiele diagram, assuming only the keys to be present. This amounts to the use of a binary system with an equivalent reflux ratio. The method of the present paper as given by Equations (12) and (13) likewise amounts to the replacement of the actual system by an equivalent binary, but with both the reflux ratio and the molal flows of the keys being replaced by equivalent quantities which differ somewhat from those used by Hengstebeck. In the present method, setting $P_r = P_s = 1$ amounts to replacing the actual L/V in the rectifying section, or ρ, by the ratio $\phi_{rh}\phi_{rl}/\alpha_h\alpha_l$ of the actual system, and making a similar change for the stripping section. From the statement of the basis (4) of Hengstebeck's approximation, it appears that it is best suited to separations involving large N and M. An assumption equivalent to setting $\phi_{rh} = \alpha_h$ and $\phi_{sl} = \alpha_l$ is also involved; this is precisely true only for sharp separations. Hengstebeck's assumptions neglect the effects in the rectifying section of the outside lights near the top of the column and of the outside heavies just above the feed plate; in the stripping section the effects of the outside heavies near the bottom of the column and of the outside lights just below the feed plate are neglected. The present method as given by Equations (7) and (8) includes these effects. The approximation given by Equations (12) and (13) retains some of such effects; the setting of $P_r = P_s = 1$ is made possible by the fact that much of the influence of the outside components cancels even within a single section. The remaining effects of the outside components are contained in the ϕ values of the keys. As shown by the definitions $\Omega_r(\phi_{rl}) = 0$, $\Omega_s(\phi_{sl}) = 0$, the numerical value of each ϕ depends upon the amounts and volatility ratios of all components present.

Example Calculations

The statements of the examples considered in this paper are given in Table 1.

Examples 1, 2, and 4 were selected for the purpose of comparing the plate requirements as given by various algebraic equations with that obtained by use of the "r-equations," Equations (7) and (8). This comparison is given in Table 2. The most accurate figures, and the most easily ob-

TABLE 3.—CALCULATION OF ϕ_{fl} AND THE MINIMUM REFLUX RATIO FOR EXAMPLE 2

Calculation of ϕ_{fl}

Assumed $\phi_{fl} = \phi_a = 0.585$

Comp. No.	Rel. Col. α	αX_f	$(\alpha - \phi_a)$	$\dfrac{\alpha X_f}{\alpha - \phi_a}$	$\dfrac{\alpha X_f}{(\alpha - \phi_a)^2}$
1	0.25	0.0280	−0.3350	−0.074627	0.22277
2	0.50	0.1125	−0.0850	−1.3235	15.571
3	1.00	0.450	0.4150	1.0843	2.6128
4	2.00	0.450	1.4150	0.31802	0.22475
				0.00419	18.631

$$-(1-q) = 0.0000$$

$$\Omega_f(\phi_a) = 0.00419$$

$$\phi_{fl} = \phi_a - \frac{\Omega_f(\phi_a)}{\Omega'_f(\phi_a)}$$

$$\phi_{fl} = 0.585 - \frac{0.00419}{18.631} = 0.58478^*$$

Calculation of Minimum Reflux Ratio

D_{xD}	αD_{xD}	$(\alpha - \phi_{fl})$	$\dfrac{\alpha D_{xD}}{\alpha - \phi_{fl}}$
....	....	....	....
0.010714	0.005357	−0.08478	−0.063187
0.42858	0.42858	0.41522	1.0322
0.22500	0.45000	1.41522	0.31797
D = 0.66429			V_r = 1.2870

$$\text{Min. Reflux Ratio} = \frac{V_r}{D} - 1 = 1.9374 - 1 = 0.9374$$

* Recalculation shows that this value is correct to five significant figures.

TABLE 4.—CACULATION OF ϕ_{rh} AND ϕ_{sh} FOR EXAMPLE 2

Calculation of ϕ_{rh}

Assumed $\phi_{rh} = \phi_a = 0.483$

Comp. No.	Rel. Vol. a	aD_{xD}	$(a-\phi_a)$	$\frac{aD_{xD}}{(a-\phi_a)}$	$\frac{aD_{xD}}{(a-\phi_a)^2}$
1	0.25	....	.....	....	....
2	0.50	0.005357	0.017	0.31512	18.536
3	1.00	0.42858	0.517	0.82897	1.6034
4	2.00	0.45000	1.517	0.29664	0.19554
				1.4407	20.335

$$-V_r = -1.4427$$

$$\Omega_r(\phi_a) = -0.0020$$

$$\frac{L_r}{D} = \left(\frac{L_r}{D}\right)_{min} \times 1.25 = 1.1718$$

$$V_r = \left(\frac{L_r}{D} + 1\right) D = 1.4427$$

$$\phi_{rh} = \phi_a - \frac{\Omega_r(\phi_a)}{\Omega'_r(\phi_a)}$$

$$\phi_{rh} = 0.483 + \frac{0.002}{20.335}$$

$$\phi_{rh} = 0.48310$$

Calculation of ϕ_{sh}

Assumed $\phi_{sh} = \phi_a = 0.576$

$B_{xB} = 1 - D_{xD}$	aB_{xB}	$(a-\phi_a)$	$\frac{aB_{xB}}{(a-\phi_a)}$	$\frac{aB_{xB}}{(a-\phi_a)^2}$
0.1000	0.025	−0.326	−0.076687	0.23524
0.21429	0.10715	−0.076	−1.4099	18.551
0.021424	0.021424	0.424	0.050526	0.11917
....	....	.....	....	....
B = 0.33571		−1.4361		18.905

$$V_s = 1.4427$$

$$\Omega_s(\phi_a) = 0.0066$$

$$V_s = V_r = 1.4427$$

$$\phi_{sh} = \phi_a - \frac{\Omega_s(\phi_a)}{\Omega'_s(\phi_a)}$$

$$\phi_{sh} = 0.575 - \frac{0.0066}{18.905}$$

$$\phi_{sh} = 0.57565$$

tained, are those from the r-equations. The agreement with the s, S equations (*7*) is good, but the difficult trial and error involved in using the original equations (*6*) leads to some error in these results.

Example 3 was selected to illustrate the determination of plate requirements for systems in which the feeds are partially vaporized. Examples 5, 6, and 7 were selected in order to study the nature of P_r and P_s.

For purposes of numerical illustration, Example 2 was selected. In Table 3, the steps involved in the determination of the minimum reflux ratio (*10*) for this example are shown.

The economic optimum reflux ratio is often not far above the minimum. Using a value of reflux ratio equal to $1.25(x)$ minimum, the vapor flows (V_r and V_s) are then calculated as shown in Table 4. Having evaluated V_r and V_s, the corresponding ϕ values (ϕ_{rh}, ϕ_{sh}, ϕ_{rl} and ϕ_{sl}) are calculated in the manner illustrated in Table 4.

Knowing the ϕ values corresponding to the keys, r_l for optimum feed plate location is given by Equation (11).

If it is desired to evaluate P_r and P_s, the remaining ϕ values must be determined. For all components heavier than the heavy key $\phi_{sH} \cong a_H$, and for components lighter than the light key $\phi_{rL} \cong a_L$. The ϕ_{sH}'s and ϕ_{rL}'s are calculated in the same manner as that shown for ϕ_{sh} and ϕ_{rl} in Table 4. P_r and P_s are then evaluated by substituting the ϕ values in the defining equations for the P's. These values for Example 2 are shown in Table 5.

Upon evaluation of P_r and P_s, the plate requirements N and M are readily calculated as shown in Table 5. In addition, the determination of N^* and M^* is also shown.

For systems in which the thermal condition of the feed is other than boiling point liquid, the determination of plate requirement is carried out in a manner similar to that shown in Tables 3-5. In Tables 3 and 4, the thermal condition of the feed must be taken into consideration in evaluating $(1-q)$, and the vapor and liquid flows. In Table 5, the g ratios for boiling point liquid feed are unity, but for any other thermal condition of the feed, the expression to be used is obtained by referring to Table *A-III*. For Example 3 the feed is partially vaporized. The indicated expressions are

$$\frac{g_{rl}}{g_{rh}} = \frac{(A_f + \phi_{rl})}{(A_f + \phi_{rh})}$$

and

$$\frac{g_{sh}}{g_{sl}} = \frac{(A_f + \phi_{sh})}{(A_f + \phi_{sl})}$$

A_f is the root of the flash equation shown in Table *A*-III.

In Table 6 the P values are listed for all seven examples, as well as the corresponding N and M, and N^* and M^*. As a check on the last three examples, plate-to-plate calculations were made.

One of the most difficult problems encountered in plate-to-plate calculations is the determination, by trial, of the amounts of outside heavy components in the top product and the amounts of outside light components in the bottom product. Without advance information, several plate-to-plate trials are necessary to obtain a satisfactory match at the feed plate.

It is possible to derive, from the equations given in the original manuscript expressions for the moles of an outside heavy component in the top product and the moles of an outside light component in the bottom product. Values of Dx_{DH} and Bx_{BL}, calculated by use of these expressions, give quite satisfactory matches at the feed plate upon carrying out the necessary plate-to-plate calculations.

For further comparison, the plate requirements obtained by use of the empirical method of Brown and Martin (*2*) and Hengstebeck (*4*) are given in Table 6. The percentage error was calculated on the basis of $N+M$ obtained by use of Equations (*7*) and (*8*). It is to be noted that for all examples considered, setting $P_r = P_s = 1$ gives a value of $(N^* + M^*)$ slightly

TABLE 5.—DETERMINATION OF N AND M, N^* AND M^* FOR EXAMPLE 2

Summary of ϕ Values

$\phi_{rh} = 0.48310$ $\phi_{sh} = 0.57565$

$\phi_{rl} = 0.62922$ $\phi_{sl} = 1.0178$

Solving Equation (11) gives

$r_l = 0.58943$

By Table *A*-3

$$\frac{g_{rl}}{g_{rh}} = 1; \quad \frac{g_{sh}}{g_{sl}} = 1$$

Determination of N

(1) $P_r = 0.99652$

(2) $\beta_r = \frac{g_{rl}}{g_{rh}} \frac{\phi_{rh}}{\phi_{rl}} \frac{(\phi_{rl} - a_h)(a_l - \phi_{rl})}{(a_h - \phi_{rh})(a_l - \phi_{rh})} = 4.2106$

(3) $\frac{r_l - \phi_{rh}}{\phi_{rl} - r_l} = 2.6723$

(4) $N = \frac{\log\ (1)(2)(3)}{\log \frac{\phi_{rl}}{\phi_{rh}}} = 9.15$

(5) For $P_r = 1.0$

$$N^* = \frac{\log\ (2)(3)}{\log \frac{\phi_{rl}}{\phi_{rh}}} = 9.16$$

Determination of M

(1) $P_s = 0.94141$

(2) $\beta_s = \frac{g_{sh}}{g_{sl}} \frac{\phi_{sl}}{\phi_{sh}} \frac{(\phi_{sh} - a_h)(a_l - \phi_{sh})}{(\phi_{sl} - a_h)(\phi_{sl} - a_l)} = 6.1582$

(3) $\frac{\phi_{sl} - r_l}{r_l - \phi_{sh}} = 31.086$

(4) $M = \frac{\log\ (1)(2)(3)}{\log \frac{\phi_{sl}}{\phi_{sh}}} - 1 = 8.11$

(5) For $P_s = 1.0$

$$M^* = \frac{\log\ (2)(3)}{\log \frac{\phi_{sl}}{\phi_{sh}}} - 1 = 8.22$$

TABLE 6.—PLATE REQUIREMENTS BY VARIOUS ALGEBRAIC AND NON-ALGEBRAIC METHODS

Example No.	P_r	P_s	N	N^*	N Hengstebeck (4)	N Plate-to-Plate	M	M^*
1	1.0094	0.97810	4.29	4.27	5.14	....	4.66	4.69
2	0.99652	0.94141	9.15	9.16	9.14	....	8.11	8.22
3	0.99309	0.95119	9.72	9.75	9.50	....	6.60	6.69
4	1.0509	0.83547	18.96	18.70	....	....	19.13	20.00
5	1.0371	0.76136	8.79	8.62	6.97	9.29	8.02	8.46
6	0.79902	1.1423	8.60	9.70	8.76	8.60	8.37	8.11
7	0.98939	0.51508	8.02	8.08	3.83	8.00	8.21	9.24

Example No.	M Hengstebeck (4)	M Plate-to-Plate	$N + M$	$N^* + M^*$	$N + M$ Hengstebeck (4)	$N + M$ Plate-to-Plate	$N + M$ Brown and Martin (2)
1	3.89	....	8.95	8.96	9.03	.....	8.85
2	7.33	....	17.26	17.38	16.47	.....	15.55
3	6.30	....	16.32	16.44	15.80	.....	14.99
4	....	....	38.09	38.70	.....	.....	39.44
5	7.23	6.78	16.81	17.08	14.20	16.07	15.55
6	6.17	8.37	16.97	17.81	14.96	16.97	15.55
7	7.08	8.08	16.23	17.32	10.91	16.08	15.55

* Plate requirements are, for the sake of comparison, shown to more figures than would be justified in any actual case.

Example No.	Per Cent Error of $N^* + M^*$	Per Cent Error of Hengstebeck's $N + M$	Per Cent Error of Brown & Martin's $N + M$
1	+0.11	+ 0.89	−1.12
2	+0.70	− 4.58	−9.91
3	+0.74	− 3.19	−8.15
4	+1.60	.....	+3.54
5	+1.61	−15.53	−7.50
6	+4.95	−11.84	−8.37
7	+6.72	−32.78	−4.19

greater than $(N + M)$, so that the approximation is conservative.

Nature of P_r and P_s. In the quantities P_r and P_s, c values of ϕ_r and c values of ϕ_s are involved. The determination of all of these roots and the evaluation of the functions themselves are laborious tasks. Actually, the products $P_r\beta_r$ and $P_s\beta_s$ can be reduced to expressions involving only the four ϕ's corresponding to the keys, but these expressions also are complicated and their evaluation is again laborious.

When a binary mixture is considered, it follows (by definition) that $P_r = P_s = 1$. For a multicomponent mixture the P's depend primarily upon the percentage of keys present in the feed, and secondarily upon the symmetry of the feed. Examples 5, 6, and 7 (Table 1) were selected for the purpose of investigating the above dependency. Although the P's vary considerably from unity, the equations by which N and M are calculated are relatively insensitive to the precise values of the P's. The error involved is small, unless the keys make up only a small fraction of the feed. Theoretical considerations lead to the same conclusions. For ordinary feeds, the effort required to evaluate P_r and P_s is not justified.

Conclusions

For doublet separations the plate requirement at optimum feed plate location can be determined by use of Equations (7), (8), and (11). These equations, evaluated with much less effort than those proposed previously (6, 7), give the optimum feed plate location analytically, thereby eliminating the necessity for the usual graphical solution. For other feed plate locations, r_l may be eliminated from Equations (7) and (8), and one equation in N and M obtained. Alternatively, values can be assigned to r_l (within the range $\phi_{sh} < r_l < \phi_{rl}$) and the corresponding rectifying and stripping plates calculated.

For the examples considered herein, the approximate method, Equations (12) and (13), is sufficiently accurate for ordinary purposes. In this method r_l is again obtained from Equation (11). For all examples considered, the error in plate requirements is positive. It can be seen from Table 6, that this error only becomes appreciable when the feed contains only a small amount of the keys. Regardless of the number of components, only four ϕ values must be calculated for use in the approximate method. If minimum reflux is to be calculated, one additional ϕ value is needed (ϕ_{fl}). For an ordinary system, it is estimated that the minimum reflux ratio as well as the number of rectifying and stripping plates can be calculated in four hours or less.

The approximate method is similar in principle to that of Hengstebeck (4), although differing in detail. It is apparently more reliable than either the method of Hengstebeck or that of Brown and Martin (2), for constant $-\alpha$ separations.

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Notation

a = coefficient in equation for rectifying section, Equation (A-1); defined by Equation (A-4)

A_f = a function of thermal condition of a partially vaporized feed; equal to $L_f/V_f(K)_{fb}$

b = coefficient in equation for stripping section, Equation (A-8); defined by Equation (A-11)

B = total moles of bottom product per mole of feed

c = total number of components

D = total moles of top product per mole of feed

g_{rf}, g_{sf} = functions of thermal condition of feed, appearing in equations in Table A-II; defined for a feed of any thermal condition by Table A-III

(K) = vapor-liquid molal equilibrium ratio, y/x;

$(K)_b$ = vapor liquid equilibrium ratio, y/x, of base component (i.e., component for which $\alpha = 1$) $= \dfrac{1}{\sum_c \alpha_i x_i} = \sum_c y_i/\alpha_i$

L_r, L_s = molal flows of liquid (per mole of feed) in rectifying and stripping sections, respectively

m = plate number in stripping section, numbering up from the bottom; m is zero for the reboiler, one for bottom plate

M = m for feed plate. M equals number of stripping plates including feed plate, but excluding reboiler

M^* = number of stripping plates including feed plate, but excluding reboiler, obtained by setting $P_r = P_s = 1$

n = plate number in rectifying section numbering down from top; n is zero for top plate

N = n for feed plate. N equals number of rectifying plates (excluding feed plate)

N^* = number of rectifying plates (excluding feed plate); obtained by setting $P_r = P_s = 1$

$$P_r = \prod_{j=1}^{h-1} \frac{\left(1-\frac{\phi_{sj}}{\phi_{rh}}\right)\left(1-\frac{a_j}{\phi_{rl}}\right)}{\left(1-\frac{\phi_{sj}}{\phi_{rl}}\right)\left(1-\frac{a_j}{\phi_{rh}}\right)} \prod_{j=l+1}^{c} \frac{\left(1-\frac{\phi_{rj}}{\phi_{rh}}\right)\left(1-\frac{a_j}{\phi_{rl}}\right)}{\left(1-\frac{\phi_{rj}}{\phi_{rl}}\right)\left(1-\frac{a_j}{\phi_{rh}}\right)}$$

$$P_s = \prod_{j=1}^{h-1} \frac{\left(1-\frac{\phi_{sj}}{\phi_{sl}}\right)\left(1-\frac{a_j}{\phi_{sh}}\right)}{\left(1-\frac{\phi_{sj}}{\phi_{sh}}\right)\left(1-\frac{a_j}{\phi_{sl}}\right)} \prod_{j=l+1}^{c} \frac{\left(1-\frac{\phi_{rj}}{\phi_{sl}}\right)\left(1-\frac{a_j}{\phi_{sh}}\right)}{\left(1-\frac{\phi_{rj}}{\phi_{sh}}\right)\left(1-\frac{a_j}{\phi_{sl}}\right)}$$

q = heat required to bring one mole of feed from inlet to feed-plate temperature and vaporize it, divided by latent heat of vaporization of feed

r_j = j'th root of Equations (2) and (3), respectively

s_j, s'_j = rectifying functions; defined by Equations (A-14) and (A-15) respectively

S_j, S'_j = stripping section functions; defined by Equations (A-16) and (A-17) respectively

V_r, V_s = molal flows of vapor (per mole of feed) in rectifying and stripping sections, respectively

V_f = moles of feed vaporized at feed plate conditions per mole of feed

x_{ni} = mole fraction of i'th component on plate n

x_{mi} = mole fraction of i'th component on plate m

X_{fi} = mole fraction of i'th component in total feed

x_{fi} = mole fraction of i'th component in liquid part of feed after flashing

y_{fi} = mole fraction of i'th component in vapor part of feed after flashing

y_{ni} = mole fraction of i'th component in vapor from plate n

y_{mi} = mole fraction of i'th component in vapor from plate m

SUBSCRIPTS:

a = assumed value of ϕ, ϕ_a. (*See* Tables 2 and 3)

B = bottom product

c = all components, total number of components, or component having largest α value (as indicated by context)

D = top product

f = column feed

h = heavy or less volatile key component

H = any component for which α is less than α_h

i, j = component numbers (between 1 and c). Components are arranged in order of increasing volatility, 1 being the least volatile and c being the most volatile

l = light or more volatile key component

L = any component for α is greater than α_l

m = plate number m stripping section (see above)

n = plate number in rectifying section (see above)

r = rectifying section

s = stripping section

GREEK LETTERS:

α = volatility ratio of individual components; $\alpha_i = (K)_i/(K)_h$

β_r = product of factors; defined by Equation (9)

β_s = product of factors; defined by Equation (10)

$\prod$ = product of factors

$$\prod_{j\neq i} \left(1-\frac{\phi_{ri}}{\phi_{rj}}\right) = \left(1-\frac{\phi_{ri}}{\phi_{r1}}\right)\left(1-\frac{\phi_{ri}}{\phi_{r2}}\right) \cdots \left(1-\frac{\phi_{ri}}{\phi_{ri-1}}\right)\left(1-\frac{\phi_{ri}}{\phi_{ri+1}}\right) \cdots \left(1-\frac{\phi_{ri}}{\phi_{rc}}\right)$$

$\rho = L_r/V_r$ (molal ratio of liquid to vapor flows) in rectifying section

$\sigma = V_s/L_s$ (molal ratio of vapor to liquid flows) in stripping section

$\sum$ = summation symbol.

$\sum_c$ = sum over all components

(*Notation continued on page 260*)

Appendix

TABLE A-I.—DISTILLATION EQUATIONS OF REFERENCE (6) IN PRESENT NOTATION

Rectifying Section

$$\frac{y_{ni}}{(1-\rho)x_{Di}} = \frac{\sum_{j=1}^{c} \frac{a_j \phi_{rj}^{-n}}{1-\frac{\phi_{rj}}{\alpha_{ri}}}}{\sum_{j=1}^{c} a_j \phi_{rj}^{-n}} \qquad (A\text{-}1)$$

$$\frac{x_{ni}}{\left(\frac{1-\rho}{\rho}\right)x_{Di}} = \left(\frac{1}{\alpha_{ri}}\right)\frac{\sum_{j=1}^{c} \frac{a_j \phi_{rj}^{-(n+1)}}{1-\frac{\phi_{rj}}{\alpha_{ri}}}}{\sum_{j=1}^{c} a_j \phi_{rj}^{-n}} \qquad (A\text{-}2)$$

$$(K)_{nh} = \frac{\rho \sum_{j=1}^{c} a_j \phi_{rj}^{-(n+1)}}{\sum_{j=1}^{c} a_j \phi_{rj}^{-n}} \qquad (A\text{-}3)$$

$$a_i = \frac{\prod_{j=1}^{c} \left(1-\frac{\phi_{ri}}{\alpha_{rj}}\right)}{\prod_{j\neq i} \left(1-\frac{\phi_{ri}}{\phi_{rj}}\right)} \qquad (A\text{-}4)^*$$

$$\Omega_r(\phi_{ri}) = \sum_{j=1}^{c} \frac{D x_{Dj}}{1-\frac{\phi_{ri}}{\alpha_{rj}}} - V_r = 0 \qquad (A\text{-}5)$$

$$\prod_{j=1}^{c} \phi_{rj} = \rho \prod_{j=1}^{c} \alpha_{rj} \qquad (A\text{-}6)^*$$

$$\Omega_f(\phi_{fi}) = \sum_{j=1}^{c} \frac{X_{fj}}{1-\frac{\phi_{fi}}{\alpha_j}} - (1-q) = 0 \qquad (A\text{-}7)$$

Stripping Section

$$\frac{y_{mi}}{\left(\frac{1-\sigma}{\sigma}\right)x_{Bi}} = \frac{\sum_{j=1}^{c} \frac{b_j \phi_{sj}^{m+1}}{\frac{\phi_{sj}}{\alpha_{si}}-1}}{\sum_{j=1}^{c} b_j \phi_{sj}^{m+1}} \qquad (A\text{-}8)$$

(*Appendix continued on page 260*)

Notation

(*Continued from page 259*)

ϕ_{fi} = i'th root Equation (*A*-7), (i = 1 to c) $\alpha_{i-1} < \phi_{fi} < \alpha_i$
ϕ_{ri} = i'th root of Equation (*A*-5), (i = 1 to c) $\alpha_{i-1} < \phi_{ri} < \alpha_i$
ϕ_{si} = i'th root of Equation (*A*-12), (i = 1 to c) $\alpha_i < \phi_{si} < \alpha_{i+1}$
$\Omega_r(\phi)$ = rectifying section function; defined by Equation (*A*-5)
$\Omega_s(\phi)$ = stripping section function; defined by Equation (*A*-12)
$\Omega_f(\phi)$ = function defined by Equation (*A*-7)
$\Omega'_r, \Omega'_s,$
Ω'_f = first derivative of indicated function with respect to ϕ

Appendix

(*Continued from page 259*)

Stripping Section

$$\frac{x_{mi}}{(1-\sigma)x_{Bi}} = \left(\frac{1}{\alpha_{si}}\right)\frac{\sum_{j=1}^{c}\frac{b_j\phi_{sj}^{m+1}}{\frac{\phi_{sj}}{\alpha_{si}}-1}}{\sum_{j=1}^{c} b_j\phi_{si}^{m}} \qquad (A\text{-}9)$$

$$(K)_{mb} = \left(\frac{1}{\sigma}\right)\frac{\sum_{j=1}^{c} b_j\phi_{sj}^{m}}{\sum_{j=1}^{c} b_j\phi_{sj}^{m+1}} \qquad (A\text{-}10)$$

$$b_i = -\frac{\prod_{j=1}^{c}\left(1-\frac{\phi_{si}}{\alpha_{sj}}\right)}{\prod_{j\neq i}\left(1-\frac{\phi_{si}}{\phi_{sj}}\right)} \qquad (A\text{-}11)^*$$

$$\Omega_s(\phi_{si}) = \sum_{j=1}^{c}\frac{Bx_{Bj}}{1-\frac{\phi_{si}}{\alpha_{sj}}} + V_s = 0 \qquad (A\text{-}12)$$

$$\prod_{j=1}^{c}\phi_{sj} = \frac{1}{\sigma}\prod_{j=1}^{c}\alpha_{sj} \qquad (A\text{-}13)^*$$

Whole Column

Feed Partially Vaporized

$$\frac{Dx_{Di}}{Bx_{Bi}} = -\frac{\sum_{j=1}^{c} a_j\phi_{rj}^{-N}}{\sum_{j=1}^{c} b_j\phi_{sj}^{M+1}} \cdot \frac{\sum_{j=1}^{c}\frac{b_j\phi_{sj}^{M+1}}{1-\frac{\phi_{sj}}{\alpha_{si}}} - \frac{V_f y_{fi}}{Bx_{Bi}}\sum_{j=1}^{c} b_j\phi_{sj}^{M+1}}{\sum_{j=1}^{c}\frac{a_j\phi_{rj}^{-N}}{1-\frac{\phi_{rj}}{\alpha_{ri}}}} \qquad (A\text{-}14)$$

$$V_r - V_s \equiv 1 - q = V_f,$$
$$L_s - L_r \equiv q = L_f$$

* See Notation for $\prod_{j\neq i}$

TABLE *A-II*.—DEFINITIONS OF s_j, s_j', S_j, and S_j'

Rectifying Section

$$s_j = g_{rj}\frac{a_j}{a_k}\left(\frac{\phi_{rk}}{\phi_{rj}}\right)^N \qquad (A\text{-}15)$$

$$s_j' = \frac{s_j}{\sum_{j=1}^{c}\frac{a_j}{a_k}\left(\frac{\phi_{rk}}{\phi_{rj}}\right)^N} \qquad (A\text{-}16)$$

Stripping Section

$$S_j = g_{sj}\frac{b_j}{b_i}\left(\frac{\phi_{sj}}{\phi_{si}}\right)^{M+1} \qquad (A\text{-}17)$$

$$S_j' = \frac{S_j}{\sum_{j=1}^{c}\frac{b_j}{b_i}\left(\frac{\phi_{sj}}{\phi_{sk}}\right)^{M+1}} \qquad (A\text{-}18)$$

Literature Cited

1. Alder, B. J., and Hanson, D. N., *Chem. Eng. Progress*, **46**, 48 (1950).
2. Brown, G. G., and Martin, H. F., *Trans. Am. Inst. Chem. Engrs.*, **35**, 679 (1939).
3. Harbert, W. D., *Ind. Eng. Chem.*, **37**, 1162 (1945).
4. Hengstebeck, R. J., *Trans. Am. Inst. Chem. Engrs.*, **42**, 309 (1946).
5. Holland, C. D., Thesis, The A. and M. College of Texas (August, 1949).
6. Murdoch, P. G., *Chem. Eng. Progress*, **44**, 855 (1948).
7. Murdoch, P. G., *Chem. Eng. Progress*, **46**, 36 (1950).
8. Scheibel, E. G., *Petroleum Refiner*, **27**, No. 4, 92 (1948).
9. Sokolnikoff, I. S., and Sokolnikoff, E. S., "Higher Mathematics for Engineers and Physicists," McGraw-Hill Book Co., Inc., New York, pp. 97-101 (1941).
10. Underwood, A. J. V., *J. Inst. Pet.*, **32**, 614 (1946).
11. Underwood, A. J. V., *Chem. Eng. Progress*, **44**, 603 (1948).
12. Underwood, A. J. V., *Chem. Eng. Progress*, **45**, 609 (1949).

TABLE *A*-III.—VALUES OF g_{rj} AND g_{sj}

Thermal Conditions of Feed at Feed Plate Pressure	g_{rj}†	g_{sj}†
Supercooled	$\frac{1}{V_r}$	$\frac{1}{V_s}$
Boiling Point Liquid	1	1
Partially Vaporized	$V_f\left(A_f + \frac{\alpha_{fi}}{\alpha_{ri}}\phi_{rj}\right)$	$V_f\left(A_f + \frac{\alpha_{fi}}{\alpha_{si}}\phi_{sj}\right)$
Dew Point Vapor	$\frac{\alpha_{fi}\phi_{rj}}{\alpha_{ri}}$	$\frac{\alpha_{fi}\phi_{sj}}{\alpha_{si}}$
Superheated	$\frac{\alpha_{fi}\phi_{rj}}{\alpha_{ri}L_r}$	$\frac{\alpha_{fi}\phi_{sj}}{\alpha_{si}L_s}$

where

$$A_f = \frac{L_f}{V_f(K)_{fb}}$$

and $(K)_{fb}$ is the vapor-liquid equilibrium ratio of the base component at the temperature and pressure of the feed after flashing in the column. The quantity A_f is calculated from the flash equation

$$V_f = \sum_{i=1}^{c}\frac{X_{fi}}{1+\frac{A_f}{\alpha_{fi}}}$$

† Note that if α is constant throughout, the α ratios are replaced by unity in the definitions of g_r and g_s.

THE CORN WET MILLING INDUSTRY

DEVELOPMENTS IN WET-STARCH PROCESS

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THE corn wet milling industry is one which supplies a product—cornstarch—known and used by many people in a direct or indirect form. Yet the process by which the starch and other products from corn are produced is known to relatively few. In order, then, to discuss the recent developments in wet-starch processing, this paper describes briefly the basic process first so that the value of the improved methods and equipment will be more readily understood.

The wet-starch portion of the over-all wet milling process usually consists of those sections which receive the corn into the plant and process it to the point where the starch is washed and is ready to be sent on for the preparation of starch products. Such products comprise laundry starch, special starches for industry, and food starches, including those converted to corn syrup and sugar (dextrose).

Wet-starch process operations may be considered as a series of separations. The corn kernel consists essentially of starch, protein, oil, fiber, and solubles. The bulk of the protein is in the gluten fraction and is customarily referred to as gluten. The process, then, separates in a liquid medium: (1) the oil-bearing germ from the rest of the kernel; (2) the coarse and fine fiber from the starch and gluten; (3) gluten from the starch; (4) the bulk of the liquid from the gluten, and (5) the solubles from the starch.

In the process of making these separations, portions of some streams are recycled; however, only the forward movement of the main stream will be discussed here. Further, the water balance in the system is an important feature in the process, but it will not be described other than to point out that the wet-starch process is "bottled-up." This means that no process water is sent to the sewer. The only fresh water added to the system is that which is used to wash the starch in the final stage of the wet-starch process. This water moves in a generally countercurrent manner through the process. Ultimately it is evaporated, and the concentrated solubles (heavy steepwater) are added to the animal feed.

Operation of the wet-starch process is essentially an art. As such, the manipulation of the various streams will vary somewhat with each supervisor. It is only within recent years that scientific control, as known to the chemical engineer, has been applied to the process. With this background in mind then, and with the help of the accompanying flow sheet (Fig. 1), a general description of the wet-starch process follows. The numbers on the appended basic flow sheet relate the equipment shown with the description in the text.

Shelled corn is received usually in box cars and is unloaded by means of a drag line scraper known as a corn shovel into a hopper under the track. From this receiver, the corn passes through cleaners which remove stones, stalks, other grains and field dirt. It may be sent then to storage in elevators, or directly to the process. The first step in the wet process is the steeping of the corn for about 48 hrs. at 125° F. to rehydrate the kernel and to soften the bond between the starch granules and the glutenous and fibrillar matrix material. The steeps (1) may be of the open type which function under atmospheric pressure, or of the closed type which operate under a few pounds gage pressure. Sulfur dioxide is used in the steep liquor for the double purpose of controlling the bacterial action, and of assisting in the softening of the matrix holding the starch granules. The lactic acid formed by bacterial action may assist in the steeping process, also.

After steeping, the softened kernels pass through suitable conveyors into the degerminators (2). These degerminators are attrition mills equipped with plates especially designed for corn germination. The purpose of this operation is to free the germ intact from the remainder of the kernel. In addition to this, much of the starch is freed by the mill action and the kernel is broken and dispersed so that the germ and starch may be separated from the fiber by subsequent operations. The germ is floated off from the remainder of the material in a sink-float type of separator (3). The liquid in the separator is a gluten-starch suspension maintained at a controlled gravity. Each of the degermination and germ separation operations is usually carried out in two stages. The germ is then washed in several steps to recover the starch using a screening device such as a reel (9) for the purpose. After washing, the germ is dewatered by a pressure-type machine such as the Davenport squeezer (10), the Zenith squeezer, or the Anderson expeller. Final dewatering is accomplished in driers (11) of the rotary type heated by steam. In order to protect the oil properties, drying is usually done in two stages. Removal of the oil from the germ and its subsequent refining are not properly part of the wet-starch division, but in smaller plants are included in this part of the organization.

After the germ has been removed, the underflow from the separators (6) passes over a reel (7) or similar screening device to separate the coarse fiber, which is essentially the hull material, from the fine fiber and grits. These grits are not to be confused with Brewers' grits which are a finished starch product. The process grits are hard particles of the kernel ranging in size from almost pin-point dimension to that of a lead pencil point. The reel filtrate containing the grits and fine fiber is passed over another screening device (8) equipped with a filter medium of bolting cloth. It should be mentioned at this point that, in wet-starch terminology, tailings consist of that material which discharges over the end of a screen, and a filtrate is the liquid portion passing through a screen. It may be, as in this case just mentioned, a mixture of water, gluten, starch, fine fiber, and grits, or a slurry of water, gluten, and starch such as passes through a bolting cloth screen, or a relatively clear water filtrate from a starch filter. The slurry filtrate of gluten and starch, then, from these latter screens (8) is known as grit starch and is sent forward. Tailings from the grit screens are combined with the coarse fiber tailings from the previous reel station (7) and the mixture is passed through Buhr mills (12) to break down the small grit particles to free the starch. At the same time starch is rubbed from the fiber in the mix. The Buhr mill discharge then passes to the next operation for the separation of fine and coarse fiber and of the starch and gluten from each of the fiber streams.

As a first step, the Buhr mill discharge is passed over a screen (13) separating the coarse fiber from the fine fiber, starch, and gluten fraction. The coarse fiber then receives several more washes on reels or other types of screen, to recover the starch which is mixed with the fiber. Following the washing, preliminary dewatering is accomplished by a pressure machine (14) such as is used in the germ channel.

Returning to the first-wash, coarse fiber screens (13), the filtrate containing the fine fiber, starch, and gluten passes over other screening devices (16) which may be reels or shakers, covered with bolting cloth. The fine fiber tailings are given several additional washes and are then sent to a filter

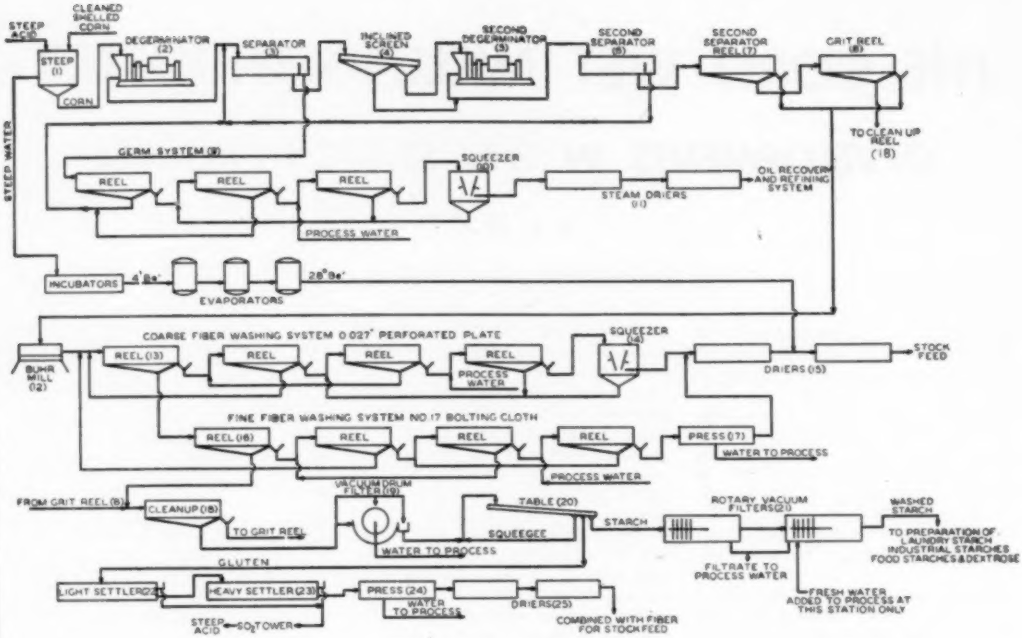

Fig. 1. Basic wet starch flow sheet.

(17) for preliminary dewatering. The filter cake is added to the dewatered coarse fiber and the mixture is sent to the driers (15). These may be two stages of rotary fire driers, or a flash drier.

The filtrate from the first-wash, fine fiber station (16) contains the gluten-starch mixture, known as mill starch, from the fiber channels, while the filtrate from the grit station (8) previously mentioned contains the mill starch freed by the milling operations. These two streams may be joined and processed directly, or the grit mill starch may be filtered and the cake added to the fiber mill starch and this mixture processed. In either case the mill starch is screened before further treatment.

In the fine fiber or grit washing systems, there is always the possibility of a tear in the bolting cloth. Fiber may get into the mill starch channel from this cause or from spillage. To remove this fiber, the mill starch is passed over clean-up reels (18).

After cleanup and possible concentration (19), separation of the starch and the gluten is accomplished by passing the mill starch over long settling tables (20). The starch settles while the gluten with some starch tails over. The tabling operation is intended to produce a prime starch. After a suitable length of time, the supply to a section of the tables is shut off and any gluten remaining on the surface or in surface pockets is removed by a stream of process water from a hose. This cut, known as squeegee, is usually returned to the table supply. The prime starch remaining on the table is then removed by a flushing operation. For the removal of the solubles remaining in the starch, the suspension is filtered on a rotary vacuum filter (21), washed on the filter, reslurried and refiltered. This refiltration is repeated, the number of times depending on the end-use requirements. After this washing procedure, the starch passes out of the wet-starch division.

Going back to the tabling operation (20), it was previously mentioned that the gluten, together with some starch, tails over the end of the tables. This gluten slurry is then settled in some style of tank (22, 23) or in a Dorr thickener. The supernatant liquid is drawn off, fortified with sulfur dioxide, and used as the steeping liquor. The thickened gluten is filtered (24), dried in rotary (25) or flash driers and then mixed with the dried fiber to form the several grades of feed.

This, then, is the general basic process. Modifications of the basic scheme are employed by some plants, and, of course, the specific operation of the several stations will vary from plant to plant.

In the past 15 years there have been several improvements of interest within the framework of the basic process. In addition, there have been three major changes in the process itself: replacement of starch tables by centrifuges; stripping and concentration of gluten by centrifugation; and elimination of the Buhr mills and the coarse fiber system by a disintegrator-pulper combination.

Of the changes within the over-all process, one is at the degerminator station (2-5) where single runner mills are replacing the old double runner machines. These latter mills frequently are belt-driven and require about a bay of space (15 ft. by 15 ft.) per unit. Leakage may exist because the supply material passes through the eye of a rotating element. The single runner mills, on the other hand, are compact, with the direct-drive motor mounted on the mill base. Two or more of these units may be installed in a bay. The supply to the mill passes through a stationary eye, thus minimizing the leakage at this point. In addition, by the use of an ammeter on the single motor the load on the mill may be more simply controlled by the operator. Another advantage is that only one set of plates needs to be balanced, thus saving a little on the cost of the plates, and on the time required to replace a set of plates in the mill.

Another improvement has been the replacement of silk bolting cloth with nylon on reels (8, 16, 18) and shakers. The nature of the silk thread permitted bacteria to lodge and multiply. Without a frequent cleaning program the openings in the silk closed up in a short time. When using nylon, the smooth thread offers little for the attachment of the bacteria, and the cleaning schedule can be extended to about once a month. Increased strength and life are other advantages of nylon.

While on the subject of nylon, the substitution of this material on starch filters has effected better performance and longer cloth life. Nylon is used to some extent on gluten filters (24) also.

The shakers and reels used in the fiber

washing stations have always presented housekeeping and maintenance problems. High humidity and sulfur dioxide concentrations make working conditions in the area unpleasant. In addition, these same conditions cause corrosion of building steel and concrete. To cope with this situation, one procedure has been to replace the old-style open shakers and reels with totally enclosed, unit-ventilated, shakers such as the Rotex, RoBall, Patterson or Link-Belt machines. A space and capacity saving results when this type screen replaces reels and old-style shakers, as well as reduction in building maintenance and improvement in working conditions.

An innovation at the first separator reel station has been the use of stationary inclined screens (4) to replace the reels. Operation at this station is simply a dewatering of the fiber to reduce the moisture content of the supply to the second pass degerminator. The inclined screens have effected considerable economy because there are no moving parts, practically no maintenance, and a considerable saving in floor space.

The corrosion problem has received much attention. Type 316 stainless steel and glass-lined iron pipe and fittings are replacing the old wood, steel, and cast iron materials.

Several new types of equipment have been tried for the replacement of various units in the treatment of gluten. A few have survived and are being used. One of the earlier attempts at gluten concentration involved use of a completely submerged filter. Two or more vacuum filter elements resembling the leaves of an American filter were operated in a gluten settler. The gluten suspension was filtered on these leaves for part of the cycle, and the cake was blown off by air or liquid during the discharge part of the cycle. In this way liquid was removed from the tank, and the slurry was concentrated by the return of the gluten filter cake. Several problems developed in this attempted use of submerged filtration and its application was not extended. A modification intended to eliminate some of the undesirable features of the submerged leaf was a tubular-type filter element operating in a cycle similar to that of the leaf. However, when this system was expanded to handle large production, it was found to be uneconomical when compared with a 55 per cent submergence, vacuum drum filter such as the Filtration Engineers, Inc. model. Of the types of equipment found satisfactory for concentration, centrifugals are the most popular. Use of the centrifugal concentration will be discussed later.

At the coarse fiber and germ squeezer stations (10, 14), use of a Zenith press has been found satisfactory. In some instances a portion of the fine fiber is mixed with the coarse fiber supply to the press.

In the drying of gluten and fiber, flash driers are being used to some extent to replace rotary units (15, 25). Some modifications in general design are necessary to prevent fires in a gluten flash drier. Moisture and temperature conditions must be controlled closely for safety, also.

Of the three major changes in the basic process, the one most generally employed throughout the wet milling industry is the use of centrifuges for primary starch separation, that is, for the partial or complete replacement of tables.

A starch table is roughly 110-120 ft. long and about 20 in. wide. Tables are built 5-6 to a section. The capacity of a table is about 100 dry bushels equivalent per day when starch is deposited to a depth of 2-2½ in. at the upper end of the table. A dry bushel is 56 lb. dry substance, and a dry bushel equivalent is that amount of dry substance at the station in question equivalent to a dry bushel input at the steeps. At this station the amount of gluten and starch normally in a dry bushel is augmented by the amount of gluten and starch in the squeegee stream per dry bushel returned to the table supply. In comparison with tables a centrifuge such as the Merco B30 with its ventbox occupies a floor space about 10 by 12 ft. However, in making a comparison with table area, the floor space occupied by the second-stage centrifuge and by the auxiliaries must be added to that of the first-pass unit. The capacity of a first-stage B30-unit is of the order of 7000-8000 dry bushel equivalent per day. Centrifuges for primary starch separation may be operated in one of two ways: a high quality gluten and a low quality starch are produced as first-stage discharges; or a low quality gluten and a high quality starch are produced. The second-stage centrifuge reworks the low quality discharge. In this country, the first procedure is generally used.

There are both advantages and disadvantages in the use of centrifuges for primary starch separation. There is a considerable time factor involved in tabling; a cycle requires about 8 hrs. In contrast, the centrifuge operation is almost instantaneous. Further, the time

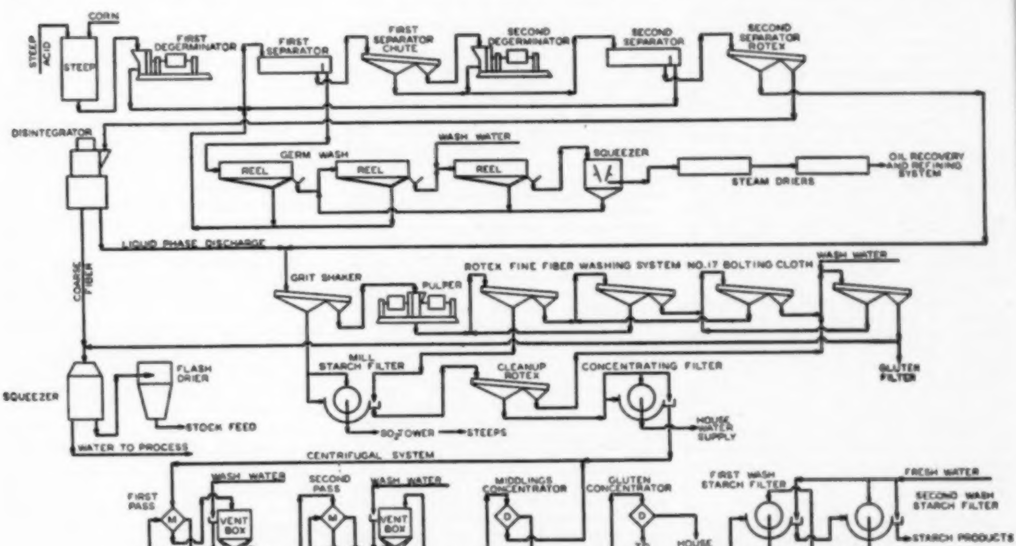

Fig. 2. Modernized wet starch flow sheet.

the starch remains on the tables permits possible contamination by bacterial action and dirt. This is avoided in the centrifuge. Building space and cost are reduced when using centrifuges. On the other hand, the first cost of a Merco centrifuge is high. In addition, an operator of higher grade is required for centrifuge operation than is required for table operation. Generally speaking, the usual two-pass centrifuge system does not produce a starch of as low a protein content as does a table. On the whole, however, the advantages of centrifugal separation seem to outweigh the disadvantages.

The gluten discharge from the first-pass primary centrifuge, while high in protein content, is low in solids concentration. This material must be thickened before filtration because a gluten high in protein and low in solids, less than 12 oz./gal., is difficult to filter. Centrifugal concentration of gluten from 2-4 oz./gal. insolubles to 14-16 oz./gal. is readily accomplished by the DeLaval nozzle-type centrifuges frequently used for this purpose. A recent addition of flushing tubes to the bowl assembly by the manufacturer has improved the operation of the concentrator. As a further advantage, use of the centrifugal concentrator eliminates need for a space- and time-consuming settler or Dorr thickener.

In connection with table operation, centrifuges are now used to strip more starch from the gluten tailings from the tables. This gluten contains about 6 oz./gal. insolubles consisting of about 40% protein, 45% starch, and 15% other material. The gluten is concentrated to 14-16 oz./gal. by settling or centrifuging before being supplied to the strippers. Good stripping operation produces a gluten of 6-8 oz./gal. insolubles containing about 60% protein and a starch discharge containing 9-11% protein. A stripper by itself may be operated to produce a high protein gluten, or a low protein starch fraction; a choice must be made as to which type of product is desired because both cannot be obtained at the same time. In an effort to obtain both, a recent modification of the stripping procedure involves the use of both strippers and restrippers. The former are set to produce a gluten of high protein content, 65-68%, and a resulting starch with a protein content of 16-20%. This starch fraction is restripped to produce a starch containing 8-9% protein. This type starch is used in the manufacture of certain specialties.

Here again, the gluten discharge from the stripper is too light for filtration. Centrifugal concentrators are used to raise the insoluble content to a value suitable for filtration. The top or liquid discharge from a concentrator so used will contain about 1 oz./gal. insolubles. As this water is used for steeping, the insolubles must be reduced to about 50 gr./gal. An effluent satisfactory for steeping is produced by allowing the gluten to rise as a foam and separate from the liquid.

The most recent major change in the basic process is the use of a disintegrator-attrition mill combination to replace the Buhr mills and the coarse fiber system. Buhr mills in one form or another have been used for centuries for grinding grain.

In the wet milling industry, the Buhr stones used are 54 in. in diam. The upper stone, known as the runner, is weighted with concrete to about 3,000 lbs. and during operation rests on the material being ground. The outer 10-12 in. of the stone are dressed to do the grinding while the inner portion contains the furrows which distribute the supply to the grinding area. Operation of a Buhr mill is a well-developed art.

However, there are few young men learning this art; that has been the lament of the older millers the past several years. In addition, the stones must be dressed frequently and good stone dressers are increasingly difficult to find. Stone dressing is somewhat dusty, and unless adequate precautions are observed, silicosis may be contracted by the stone dresser. In normal use a mill is out of service for eight hours every five days for redressing the stones. Considerable work in preparing a new stone for service is required. The stone as received has been cut roughly to size. In the preparation, the size is cut more accurately, the furrows are cut, and the stone is dressed. In addition, the rotating stone must be weighted with concrete. An operating disadvantage of the Buhr mill is that in case of failure of supply stream to the mills, the runner must be raised immediately, otherwise burning of the stone takes place. When a stone is badly burned, it must be redressed.

Most of these difficulties are overcome by use of the disintegrator-attrition mill combination. At the present, a Rietz disintegrator paired with a Bauer Bros. or Sprout Waldron pulper is used. Essentially the Rietz disintegrator is a vertical hammer mill with fixed hammers rotating at high speed in a horizontal plane inside a full 360° screen. By use of the proper screen combination, fine fiber, starch, gluten, and liquid pass through the screen and are discharged through an annular duct, while the coarse fiber discharges downward from inside the screen assembly. The coarse fiber discharge is as free of starch as the material in the old process after Buhr mill grinding and four stages of washing. In addition, the fiber is as dry as that leaving the squeezers after the fourth wash station. In other words, the coarse fiber may be delivered directly to the first-stage drier. The supply to the Rietz disintegrator contains a mixture of coarse fiber, fine fiber, and grits, all carrying attached starch. The disintegrator cleans the coarse fiber, knocks considerable starch off the fine fiber and grinds some of the grits.

To recover more starch from the fine fiber and grits in the liquid phase discharge, this fraction is screened over nylon bolting cloth, and the tailings are fed to a pulper attrition mill. This mill is a special double-runner machine having the heads mounted on shaft extensions of the motor armature. On the heads are mounted plates of a style suitable for grinding the grits. As these plates are cast, each assembly must be ground to a reasonable true plane before mounting. For control of the grinding of the grits there is a fine adjustment on the setting device for the plate clearance. In the operation of the mill, the plate opening is practically zero, and the plates are actually held apart against spring pressure by the material being ground. So far, no other style mill has been found which can compete economically with the pulper.

There are several advantages and economies in the use of the disintegrator-pulper combination. In the first place, four stages of coarse fiber washing and one station of squeezers are eliminated because the coarse fiber is discharged from the disintegrator clean and dry. In the second place, Buhr mills with all their attendant troubles are also eliminated. This means that a mechanic may be substituted for a miller at this station, that easily obtained perforated screens of uniform quality are substituted for irregular quality Buhr stones, that retipping of the hammers by a welding operation is substituted for stone dressing, and that because one compact 18-in. disintegrator has twice the capacity of a Buhr mill, considerable floor space is saved. In addition to these points, no adjustment of the disintegrator is involved in operation, and failure of the supply stream causes no trouble. The accompanying modernized flow sheet (Fig. 2) shows the incorporation of these developments in the wet-starch process.

Instrumentation is being used to some extent in the wet-starch processing, but there is much more to be done in this field. Temperature and flow-recording devices are being used successfully. Progress is being made in specific gravity recorders and controllers. Perhaps the most completely instrumented section of the wet process is the centrifugal station for primary starch separation. Good centrifuge operation demands constant conditions of flow rate, wash water rate, supply gravity and starch discharge gravity. Control instruments are desirable for maintaining constancy in these streams.

During the past 15 years the corn wet milling industry has begun to feel the impact of modern technology. The impact, however, has made but a dent in a structure developed, and developed well, over a span of a century as an art. Those who work in process development have discovered how hard it is to make changes or improvements which will show a saving. It is true that most of the equipment could be made to look more attractive, and that in many cases working conditions could be made more pleasant. However, the equipment and processes evolved from hard experience and by hard work on the part of those who have grown up in the industry are functionally quite efficient. Future improvements to be made by chemical engineering technology probably will be based on a better scientific understanding of corn structure and components, on a better knowledge of what really happens at each stage of the process, and on a more precise knowledge of the basic factors of chemistry and physics applying to the composition and properties of the entities involved.

(Presented at A.I.Ch.E. Kansas City (Mo.) Meeting.)

ABSTRACTS

*Abstracts of papers published in "Phase-Equilibria—Pittsburgh and Houston," Chemical Engineering Progress Symposium Series No. 2, Vol. 48 (1952). The volume may be ordered from Chemical Engineering Progress, 120 East 41st Street, New York 17, New York.**

SOME METHODS OF EXPERIMENTAL STUDY OF VAPOR-LIQUID EQUILIBRIA

B. H. Sage and H. H. Reamer

California Institute of Technology

A DISCUSSION is presented of the minimum experimental thermal, volumetric, or phase-equilibrium data required for the establishment of the phase behavior and thermodynamic properties of pure substances and mixtures. The general methods of making such measurements in both homogeneous and heterogeneous systems are described. There is also a review of the basic relationships and quantities involved in the estimation of the properties of the individual phases of a heterogeneous equilibrium. Means of presenting the properties of such systems are discussed along with the procedures for calculating values of these properties from the basic experimental data.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 3 (1952).

FUGACITY OF VAPOR MIXTURES

E. R. Gilliland and T. E. Sullivan

Massachusetts Institute of Technology

THIS paper presents experimental work on the direct determination of the fugacity of ethylene in mixtures of ethylene and nitrogen, ethylene and hydrogen, and ethylene and ethane. The fugacity of the ethylene was controlled by the use of the solid compound it formed with cuprous chloride. The experimental runs covered temperatures from 0° to 40° C. and pressures up to 4000 lb./sq.in. abs. The experimental data indicate that the Lewis and Randall fugacity rule can be greatly in error for these mixtures. Several other rules, among them Kritschewsky's, the isometric-intercept, and the partial-molal, give better agreement with the experimental data.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 18 (1952).

PREDICTION OF CRITICAL PROPERTIES AND EQUILIBRIUM VAPORIZATION CONSTANTS FOR COMPLEX HYDROCARBON SYSTEMS

M. J. Rzasa, E. D. Glass, and J. B. Opfell

Stanolind Oil and Gas Company

A CORRELATION by which convergence pressures of complex essentially paraffinic hydrocarbon systems may be estimated is presented based on a relationship between the critical pressure of the system and the product of the molecular weight and specific gravity of the heptanes plus fraction. A chart has been prepared for temperatures up to 400° F. Published experimental data on phase behavior in binary and complex hydrocarbon systems have been correlated using the convergence pressure as the variable to describe the effect of composition on the equilibrium-constant values. These values covering the range of pressures to 10,000 lb./sq.in. abs. and temperatures from 40° to 500° F. have been tabulated and charted, and an example table is presented.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 28 (1952).

DEVELOPMENT OF ISOTHERMAL AND ISOBARIC EQUATIONS—Vapor-Liquid Equilibrium in Nonideal Systems

K. T. Yu and James Coull

University of Pittsburgh

THIS paper considers the activity coefficient of a component in binary and multicomponent mixtures under isothermal and isobaric conditions. A more exact thermodynamic expression is developed and a rapid graphical solution is evolved to evaluate the constants under isothermal conditions. An isobaric equation is also presented for the activity coefficient when the standard state is consistent or inconsistent. Good agreement is obtained with experimental data.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 38 (1952).

THERMODYNAMICS OF SOLUTIONS—Analysis of Vapor-liquid Equilibria

Otto Redlich, A. T. Kister, and C. E. Turnquist

The Shell Development Company

IN the thermodynamic analysis of vapor-liquid equilibria, fundamental properties of the liquid and vapor phases are derived from experimental data collected under the most favorable conditions, mainly for binary mixtures near atmospheric pressure. These properties furnish a consistent and convenient basis for the calculation of equilibrium ratios. A system of flexible methods for thermodynamic analysis is discussed and illustrated, and an approximate equation of state is presented for use in many practical problems.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 49 (1952).

CONJUGATE LIQUID-PHASE EQUILIBRIA—C_4 Hydrocarbon-Furfural-Water Systems

John Griswold, R. V. West, and K. K. McMillin

The University of Texas

EQUILIBRIA data are presented as single-, two-, and three-phase isotherms for propane, propene, and the commercial C_4 hydrocarbons (separately) with furfural water.

Solubilities of the hydrocarbons in the furfural phase with no conjugate phase correlate consistently with temperature and water concentration. A single relation, applicable for all water concentrations and temperatures (75° to 200° F.), correlates conjugate-phase data in terms of activity coefficients for each of the hydrocarbons between liquid hydrocarbon and furfural phases and also equivalent data for the water between water and furfural phases.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 62 (1952).

EXTRACTIVE-DISTILLATION SEPARATION OF N-BUTANE FROM BUTENES-2

H. V. Hess, E. A. Naragon, and C. A. Coghlan

Beacon Laboratories of the Texas Company

VAPOR-LIQUID equilibrium data for the *n*-butane–butenes-2 system in the presence of a number of selective solvents are presented and serve as bases for selection of solvent and solvent dosage to be used in the extractive-distillation pilot plant. Superior solvents were found to be aniline and furfural modified by the addition of water. A continuous extractive-distillation pilot-plant investigation of the separation of *n*-butane from butenes-2 was carried out by use of aniline and furfural solvents.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 72 (1952).

VAPOR-LIQUID EQUILIBRIA IN THE METHANOL-STYRENE-LATEX SYSTEM

O. E. Dwyer and W. P. Gleich

University of Rochester

VAPOR-LIQUID equilibrium data obtained experimentally are compared with calculated equilibria derived from swelling measurements. The vapor-liquid equilibrium data were obtained by a static method over concentration and temperature ranges of practical interest—methanol concentrations up to a mole fraction of 0.17 on a methanol-water basis, styrene concentrations up to a styrene/polymer ratio of 0.166, and a temperature range of 30°-95° C. Very good agreement between the experimental and the calculated equilibria was obtained, indicating that swelling measurements of polymers in solution may be a useful tool in obtaining vapor-liquid equilibria for polymer-solvent systems, at least for systems that are nonpolar. These conclusions are important in the synthetic-rubber industry.

Chem. Eng. Progress Symposium Series—"Phase-Equilibria--Pittsburgh and Houston," **48**, No. 2, 80 (1952).

* *See advertisement, page 66, News Section, for details.*

(The remaining abstracts will appear in the June issue.)

CAST ALLOY REFERENCE SHEET

N. S. MOTT, Chief Chemist Metallurgist

The Cooper Alloy Foundry Co., Hillside, N. J.

ALLOY: CORROSION RESISTANT 65% NICKEL, 32% COPPER ALLOY.

APPLICATIONS AND REMARKS: Monel metal is very resistant to corrosion under reducing conditions where the stainless steels do not stand up. In the absence of air or oxidizing agents it may be used to handle solutions of sulfuric, hydrochloric, and hydrofluoric acids over a considerable range of concentrations and temperatures. It is the main metal which is used to resist halogens and halogen acids at elevated temperatures, and hot caustic solutions. Its application is widespread in the form of valves, fittings, and miscellaneous castings in the chemical pharmaceutical, food, paper and oil refining industries. Basic cost is 27 cents a pound over 18-8S.

DESIGNATIONS: CAST MONEL METAL.

CHEMICAL COMPOSITION RANGE: C < .30%; Ni 63-67%; Cu 28-32%; Si < 2%; Fe < 3.5%.

MACHINABILITY: Monel metal machines less readily than 18-8S and requires use of high speed or cemented carbide tools ground to sharp cutting edges, ample flow of cutting compound, and lower feeds and speeds. If impurities are present in the metal, tears quite often result.

HEAT TREATMENT: Not heat treated—used in "as-cast" condition.

WELDABILITY: Monel metal of high quality may be welded by arc or gas methods without danger of cracking if correct techniques are used; however, when appreciable amounts of sulfur and lead impurities are present cracking adjacent to the weld deposit may occur, especially if the carbon content is on the high side. When welding with oxyacetylene use a neutral or slightly reducing flame as an oxidizing flame will produce a brittle weld through burning, and too much acetylene may cause brittleness by introducing excessive carbon into the weld.

MECHANICAL AND PHYSICAL PROPERTIES:

Tensile Strength, 1000 lb./sq.in.	65
Yield Point, 1000 lb./sq.in.	33
Elongation, %	25
Reduction in Area, %	28
Brinell Hardness	150
Charpy Impact (Std. Keyhole ft.lbs.)	75
Mod. of Elasticity ($\times 10^6$ lb./sq.in.)	18.5
Specific Gravity	8.63
Melting Point	2400-2450°F
Specific Heat (B.t.u./(lb.)/° F.) 32-212° F.	0.13
Thermal Expansion ($\times 10^{-6}$in./(in.)/° F.) 32-212° F.	6.8
Thermal Conductivity (B.t.u./sq.ft./° F./in.) 32-212° F.	180
Electrical Resistance (Ohms./cir. mil. ft.) @ 32° F.	320

CORROSION RESISTANCE

ACIDS

Acetic 5%, 70 F	G
Acetic 5%, boiling	E
Acetic 80%, 70 F	G
Acetic 80%, boiling	E
Acetic Glacial, 70 F	G
Acetic Glacial, boiling	E
Benzoic 5%, 70 F	G
Boric 5%, 176 F	G
Chromic 10%, 70 F	G
Chromic 10%, boiling	N
Chromic 50%, boiling	N
Citric 5%, 70 F	E
Citric 25%, boiling	G
Citric 50%, boiling	G
Formic 5%, 70 F	G
Hydrochloric 1%, 70 F	G
Hydrochloric 1%, boiling	F
Hydrochloric, 5%, 70 F	F
Hydrochloric 5%, boiling	N
Hydrochloric 25%, 70 F	P
Hydrochloric 25%, 176 F	P
Hydrofluoric 48%, 70 F	E
Hydrofluoric 48%, 176 F	G
Lactic 5%, 70 F	G
Malic, all temps.	G
Nitric all concs., 70 F	N
Nitric 65%, boiling	N
Oleic all concs., all temps.	E
Oxalic 5%, boiling	G
Phosphoric 10%, 70 F	G
Phosphoric 85%, 70 F	F
Phosphoric 85%, boiling	F
Steark concentrated to 200 F	G
Sulfuric 2%, 70 F	G
Sulfuric 2%, 176 F	F
Sulfuric 2%, boiling	E
Sulfuric 5%, 70 F	G
Sulfuric 5%, 176 F	F
Sulfuric 5%, boiling	E
Sulfuric 10%, 70 F	G
Sulfuric 10%, 176 F	P
Sulfuric 10%, boiling	E
Sulfuric 78% (60° Be), 176 F	N
Sulfuric 93% (66° Be), 70 F	F
Sulfuric 93%, 300 F	N
Oleum, 70 F	N
Mixed Acids 57% H_2SO_4, 28% HNO_3, 176 F	N

ALKALIES

Ammonium Hydroxide, all concs.	F
Calcium Hydroxide Sat., 70 F	E
Calcium Hydroxide Sat., boiling	E
Sodium or Potassium, Hydroxide, all concs., 70 F	E
Sodium or Potassium Hydroxide < 20%, boiling	E
Sodium or Potassium Hydroxide 30% boiling	E
Sodium or Potassium Hydroxide, Molten, 600 F	F

NEUTRAL AND ALKALINE SALTS

Barium Sulfide, 70 F	G
Calcium Chloride 5%, 70 F	E
Calcium Sulfate Sat., 70 F	E
Magnesium Chloride 5%, 70 F	E
Magnesium Sulfate 5%, 70 F	E
Sodium Carbonate, all concs., 70 F	E
Sodium Chloride 5%, 70 F	E
Sodium Sulfate 5%, 70 F	G
Sodium Sulfide 5%, 70 F	G
Sodium Sulfite 5%, 70 F	F

ACID SALTS

Alum 10%, boiling	G
Aluminum Sulfate 10%, 70 F	G
Ammonium Chloride 5%, 70 F	G
Ammonium Sulfate 10%, 70 F	G
Ammonium Sulfate 10% boiling	G
Ammonium Nitrate, all concs., 70 F	E
Stannous Chloride 5%, 70 F	N
Zinc Chloride 5% boiling	G

OXIDIZING ALKALINE SALTS

Calcium Hypochlorite 2%, 70 F	N
Sodium Hypochlorite 5%, 70 F	N
Sodium Peroxide	G

OXIDIZING ACID SALTS

Ammonium Persulfate 5%, 70	N
Cupric Chloride 1%, 70 F	N
Cupric Sulfate 10%, 70 F	N
Ferric Chloride 10%, 70 F	N
Ferric Sulfate, boiling	N
Mercuric Chloride 2%, 70 F	N
Stannic Chloride 5%, 70 F	N

WET AND DRY GASES

Chlorine Gas Dry, 70 F	E
Chlorine Gas Wet, 70 F	N
Sulfur Dioxide Dry, 575 F	G
Sulfur Dioxide Wet, 70 F	F
Sulfur Dioxide Solution, 70 F	F
Sulfur Dioxide Spray, 70 F	F
Hydrogen Sulfide Dry	G
Hydrogen Sulfide Wet	G

ORGANIC MATERIALS

Acetone, 70 F	Z
Acid Sludge (50% H_2SO_4), 200 F	N
Alcohol—Methyl and Ethyl	E
Aniline Hydrochloride, 70 F	G
Benzol, 176 F	G
Carbon Tetrachloride	E
Chloroform	E
Ethyl Acetate, 70 F	E
Formaldehyde, 70 F	G
Phenol 5%, boiling	G
Refinery Crudes	G
Trichlorethylene, boiling	E

PAPER MILL APPLICATIONS

Kraft Liquor	G
Black Liquor	G
Green Liquor	G
White Liquor	G
Sulfite Liquor, 176 F	N
Chlorine Bleach	P
Paper Makers Alum	G

PHOTOGRAPHIC INDUSTRY

Humid Atmospheres	E
Cellulose Acetate	G
Acetic Anhydride	E
Acetic Acid + .1% H_2SO_4	E
Developers	G
Solutions Containing SO_2	F
Silver Nitrate, 70 F	N

FERTILIZER MANUFACTURING

$H_3PO_4 + H_2SO_4 + HF$	P

PICKLING OPERATIONS

H_2SO_4 + Dichromate 176 F	N
H_2SO_4 + HCl, 176 F	G

CORROSIVE WATERS

Acid Mine Water	F
Abrasive Acid Mine Water	N
Sea Water	E
Brackish Water	G

FOOD & ASSOCIATED PRODUCTS

Brines	E
Edible Oils	E
Fats	E
Fatty Acid Distillation	G
Fruit Juices	G
Ketchup	G
Milk Pasteurizing	G
Vinegar and Salt, 70 F	F

RATINGS:

E—*Excellent resistance. 0.00½ max. in. per year of penetration. Corrosion so slight as to be harmless.*
G—*Good resistance. 0.00½-0.0½2 in. per year of penetration. Satisfactory service expected; at most a slight etch.*
F—*Fair resistance. 0.0½2-0.120 in. of penetration per year. Satisfactory service under specific conditions. Light to moderate attack.*
P—*Poor resistance. 0.120-0.½20 in. of penetration per year. Satisfactory for temporary service only.*
N—*No resistance. 0.½20 min. in. of penetration per year. Rate of attack too great for any use.*
†—*Subject to pitting type corrosion.*

No. 9

(NINTH OF A SERIES OF TEN)

CO-OPERATION BIG SHOT

F. J. VAN ANTWERPEN

A TEST nuclear detonation, such as was recently demonstrated over Yucca Flats, Nevada, is not the culmination of an atomic test, it is approximately the halfway point. From the spectators' view it is the most spectacular of any of the revealed way points on the road to understanding nuclear weapons, but behind the spectacle there has been much scientific labor, and much is yet to be done after the burst. The purpose of this article is to trace, within the limits of classification, some of the scientific background necessary in making such a burst possible and in evaluating the results afterward.

Just as the development of the first bomb and the production of U_{235} and plutonium was a co-operative achievement of every scientific discipline, trade, and business, so are the atomic tests at Nevada and Eniwetok. Chemical engineers are the important cogs in making the fissionable material, and as interested partners in the enterprise, the story of the work and planning behind a test should have considerable interest. This Editor was one of the observers at News Nob on April 22, and this story concerns the scientific co-operation behind "Operation Big Shot," as it was unofficially known.

Why a Test

Compelling reasons are behind experimental nuclear explosions. Fissionable materials are expensive and rare, and the cost of such operations must be sizable. Recognizing this, the Atomic Energy Commission has standardized a procedure of test approval which ultimately reaches to the President of the United States.

Perhaps the idea for the test comes from the scientific corps. If so, the request is examined to see whether the data can be obtained in any other way except the detonation of an "experimental nuclear device." If not, and the importance of the request, along with others, is deemed sufficient, approval moves through the test director's office to the Atomic Energy Commission itself. Approval means further and final consent by the President of the United States, who is the only man in the country with the power to approve a nuclear explosion.

The recent experiment at Yucca Flats was made primarily to determine blast pressures, and to measure the velocity of the air mass surrounding the point of detonation of the device being tested.

Alvin C. Graves, test director of the Nevada proving grounds, in a briefing to the correspondents touched on the background of such tests, and the reason for them. He revealed that it is not necessary for a "weapon" to be used in order to evaluate weapons, but that the information obtained will help in their design. Here then is the primary point of test shots—more efficient use in weapons of fissionable materials.

Said Dr. Graves, "In the process of designing the best nuclear weapons, consideration is given to many different designs. A large part of the possibilities, or a large number of possibilities can be eliminated in the laboratory by experience or by theoretical computations, but eventually one is left with a choice between several different designs which cannot be eliminated without a great deal of work and effort. In such cases a field test is indicated in the interest of saving time and in the interest of getting ahead as fast as possible with the weapons. When we reach this condition the Los Alamos Scientific Laboratory decides on some sort of gadget or device which can settle the question. We often used the phrase 'experimental nuclear device or devices,' or something of that sort, and rather insisted on the use of such phrase rather than 'weapon or atomic bomb.' This is because these devices, when tested, will be simplified . . . so that they will give an answer to a single question. Moreover, one would like to minimize use of material. . . . We do not use more than is necessary. Consequently the device detonated is usually not useful as a weapon design. However, the information that is obtained will eventually affect the design of some stockpile weapon and hence improve the position of this country. . . .

"The usual design problem is set when strategic or technical considerations tell us first of all the necessary method of delivery with the attendant size and weight limitations and the required yield.

"In the field then, we will detonate these devices and design experiments to answer two basic types of questions. First, how the device operates, and second, what are the effects of such devices on material. In the first category our experiments are to determine yield and efficiency and to prove that

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CO-OPERATION BIG SHOT

(Continued from page 17)

the measured yield was not a fluke, and in the second category are all the experiments to determine neutron rays and energies as functions of time and distance, as well as tests of the protection afforded by structures, shelters, and the like. Also the converse problem of how best to attack is investigated. The tests in this series are designed to answer questions in both categories.

"The field tests we made in Eniwetok and Nevada have made it possible for us to increase efficiency and yield of stockpile weapons in sizable amounts. We cannot say in what amounts, but certainly sizable. My estimate is that the activities of the Nevada Site have about doubled our rate of acquisition of knowledge. This increase has materially improved our ability to defend our country. These tests have made it possible to design weapons for a wide variety of strategic and theoretical situations, and satisfactory to many kinds of fields."

It is in the design of these "gadgets" that nuclear physicists and armament experts co-operate to build efficiency into the A bomb. The responsibility for various models of weapons is that of the Sandia Laboratory, of the Sandia Corp. and Los Alamos Scientific Laboratory. Dr. Norris Bradbury of the latter and Dr. Donald Quarles, president of Sandia, revealed something of the purpose and method behind the different bomb designs. According to these men a basic nuclear explosion is an easy thing to obtain, but the problem before the scientists is to create efficient explosions. According to Dr. Bradbury, a critical mass is not a function of amount only, but also depends on shape, shape density and surroundings. In making an A bomb, two or more subcritical masses are combined. In making the change from the subcritical size, to the supercritical size "the role of high explosives" is studied very carefully, according to Dr. Bradbury. He further revealed that the calculation of the energy released from an exploding critical mass is not yet solved. He said that in 1945, before the first test at Alamogordo, an attempt was made to predict the energy release from the detonation, using all the then available information about such atomic processes. The results of the calculation, he continued, predicted only half of the amount actually measured when the bomb went off. Recently, the scientists worked the same problem again, only this time they used the information that six years of experiment had uncovered plus all the modern calculation devices and techniques. Results predicted an energy release for that first bomb which was twice that actually measured. This, he said, is proof of the need for actual experiment on the field in determining the answers to fundamental questions. "And," he continued, "the frequency of the tests indicates the rapidity with

which fundamental questions are being raised by atomic scientists."

Our atomic strength, Bradbury stated, is related to three basic things: the number of bombs, or production, the yield of the bombs, or efficiency, and the deliverability of the bombs. All this, he indicated, calls for the continued co-operation between the scientists and the military.

Dr. Quarles revealed that various bombs had been developed by Sandia to meet different situations efficiently. During a question period, it was stated that though there had been no fizzles or dud A bombs, there had been occasions when different designs had failed to live up to expectations as far as the generation of energy was concerned.

Weather Studies Important

For any test, weather conditions are of concern, and here another field of scientific study is called on to play a vital role. Not only must the weather be clear for an air drop (radar aiming is not used for the drops) but wind currents must also be known to prevent the atomic cloud from drifting over populated areas. Lt. Col. E. H. Karstens, of the U. S. Air Force Air Weather Service, was in charge of the meteorological survey. Weather and wind conditions for an atomic test, he said, must be pin-pointed to a 5-to-15 mile area. Data from Alaska, Japan, Hawaii, ships at sea, as well as regular weather bureaus are all used to predict conditions at the test site. Tonopah, a hundred miles to the northwest of Yucca Flats, has a full-scale weather base to warn of any last-minute local changes. Some twelve hours before the drop, the weather scientists must know what the cloud cover is going to be, must be able to predict wind currents, whether it is going to rain and where, and what the wind direction and velocities are going to be at 10,000- and 20,000-ft. levels. For the latter they use balloons and measure drift from nine Theodolite stations in the area.

All these factors are important, and an adverse report for any one of the conditions may be enough to cause postponement, even at the last moment.

Radiation Monitoring

Protection of participants, as well as those outside the test areas, is another scientific activity. The Atomic Energy Commission's Biology and Medicine Division studies effects of radiation and sets standards and working conditions for those exposed. Dr. Shields Warren spoke on the task, and said that a limit of 0.3 roentegen units a week had been

(*Continued on page* 23)

CARBIDE'S COAL-HYDROGENATION PLANT ON STREAM

An $11,000,000 coal-hydrogenation plant dedicated solely to the production of aromatic chemicals, was placed on stream in March and opened to the press for inspection last month at Institute, West Virginia, by Carbide and Carbon Chemicals Company. The new unit bids fair to make the company as much of a dominant pioneer in the commercial production of the cyclic compounds as it is in the production of straight chain aliphatics. Officials were quick to explain that the plant and the process were not designed to make fuels, but would be used solely to obtain the many chemical compounds stored in the complex macro-molecule which is coal. Carbide has been working on the problem of coal hydrogenation for some 17 years, and according to its president, J. G. Davidson, will have invested about $20,000,000 in research and plant on the problem by the end of this year. From the start, officers of the company said, the idea of splitting the coal complex into its chemical components has been the one that appealed as being the only economical approach to coal hydrogenation. To obtain fuel through hydrogenation of coal seemed to the Carbide technical organization as a marginal operation at best, especially in the United States which is well endowed with liquid fuels from petroleum.

The decision to make chemicals was founded on long market studies of the aromatic chemical supply. Except for benzene and toluene, the only source of raw material is from the by-product coke ovens of the steel industry. Effectively the supply of these chemicals, Carbide reasoned, was limited by the growth of steel production facilities. Since the steel industry is growing at a rate of about 3 to 5% a year, and the demand for products made from aromatics or its intermediates is growing at a rate, in some cases, of 25 to 36% a year, "chicken wire chemistry," as it is dubbed by the Carbide technical staff, seemed the next logical step for development.

There were other natural reasons why the field appealed. Carbide's thirty years has been spent in making synthetic organic chemicals. Knowledge and capital have made the firm the second largest chemical producer in the world, and know-how for making complex materials was ample and deep in the technical staff. Then, too, the recurrent scares about the depletion of natural gas, and the slow but steady increase in demand for natural gas as a domestic fuel, made the possibility of an expensive raw material for their aliphatic chemicals move into the realm of probability. In 1935 the research began, and an appreicable factor in creating a favorable economic condition was the fact that hydrogen, the most expensive raw material in the process was to be had in quantity at the Charleston, West Virginia, and other production units of the Company, as by-products from dehydrogenation processes. Coal, according to Dr. George T. Felbeck, vice-president of the Company, costs about ¼¢ a pound, while hydrogen is about 3 to 6 cents a pound. The availability of hydrogen for the asking overcame what might have been a major economic problem.

Technical Problems

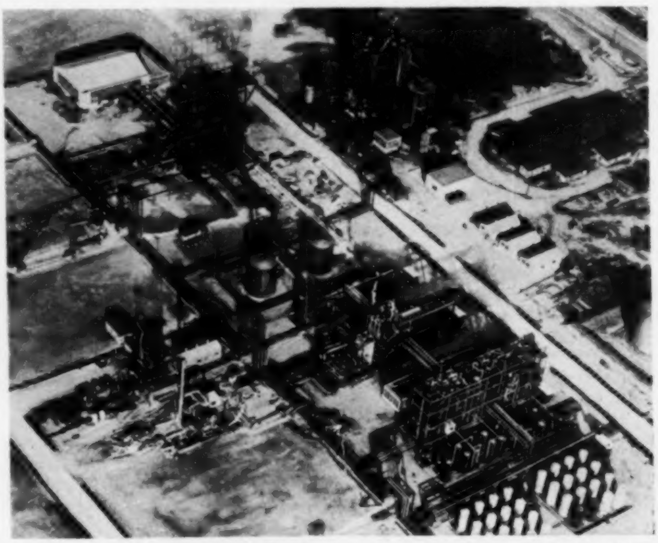
Flow charts will be shown in the June issue of "C.E.P.," but for this article, a few of the technical details are important to an understanding of the economic background. Much of the processing is similar to the German and the Bureau of Mines techniques. It is a high pressure process using about 4000 lb./sq.in. pressure and temperatures of 300 to 500° C. The heart of the process is the converter, which cokes up in a short time in operations designed for fuel. Carbide states that one of the important engineering feats of this "pilot plant" is the continuous aspect of the converter which will not coke up and require shut-downs for cleaning. Further, the amount of hydrogen used in the Carbide operation should be considerably below that of the fuel operators, since in obtaining the more complex aryl molecule from coal, less hydrogen is needed than in splitting coal into lighter gasoline products. Still another major difference created by engineering in the plant is the fact that the retention time in the hydrogenators has been reduced from nearly an hour, as in fuel installations, to a few minutes.

Recovery processes have also been improved to the point where automatic controls can well take care of the monitoring necessary for continuous production.

Pilot Plant?

Carbide considers the Institute installation a pilot plant only in the sense that it is flexible. Now on stream since the middle of March, the equipment is still being run to determine maximum operating conditions and yields. Basic conditions, such as the amount of catalyst, the optimum working pressure (it may not be a fixed pressure, it may depend on what is wanted), the best temperatures, and the proportion of

(Continued on page 22)



Air view of the new coal-hydrogenation chemicals plant opened recently at Institute, West Virginia, by Carbide and Carbon Chemicals Co. At upper right, coal storage and conveyors to grinding and coal pasting unit. Center top shows the high pressure converter installation with the hydrogen compressor building, top rear. In the center of the picture, and in order to bottom right, are the heavy products separation structure, the chemicals separation plant and the product receiving and storage tanks.

CARBIDE COAL HYDROGENATION

(*Continued from page 20*)

hydrogen are being varied in an attempt to learn production know-how impossible to obtain on laboratory equipment.

Dr. Felbeck in a talk to the editors described the philosophy behind the building of the plant as follows:

"Actually this is no pilot plant. It cost twice as much as our original plant built here at South Charleston in 1925. It is a full scale venture in the sense that at its rating of 300 tons of coal a day, we should make a profit. If we can push the capacity to 500 to 600 tons a day, as our laboratory data indicates is possible, then the project becomes extremely attractive. From an engineering standpoint, the 300-ton plant is large enough to give us data . . . in the near future to design a very large plant with assurance . . . a plant which would process around 3000 tons of coal a day."

Products

While the production of certain of the products from the pilot plant will be small, considering the national total from coal tars, there are enough of the heavy complex chemicals in the end product so as to be a factor in the market. As far as benzol is concerned, the hydrogenation process will turn out about as much for a ton of coal processed as is obtained in coking, but as the complexity of the molecule increases so does the yield comparison. From one ton of coal it is expected that, compared to coking, hydrogenation will give 5 to 8 times more naphthalene, 60 to 80 times more phenol, 300 to 500 times more quinoline, and an infinitely greater yield of aniline since it is not isolated from coke ovens.

Making Carbide even more bullish on the process is the fact that other units of the company are potential users of many of the products. Coke, one of the by-products, can be used by Electro Metallurgical Co. in its furnaces, Bakelite will use phenol for its resins, National Carbon uses pitch coke, while ethane and methane will find a ready home in the aliphatic operations of the chemical group itself.

NEW LAB. FOR DU PONT COMPANY

Plans for construction of a new $2,000,000 Haskell Laboratory of Industrial Toxicology near Newark, Del., were announced by the Du Pont Co.

This will provide enlarged facilities for the company's industrial toxicology laboratory which has been located at the Du Pont Experimental Station since 1935. The Haskell Laboratory tests Du Pont products and manufacturing processes to eliminate every potential hazard to employees and customers.

CO-OPERATION BIG SHOT

(*Continued from page* 19)

set as a safe dosage of radioactivity, which is well below the danger point.

The task of protecting the troops on the bombed Nevada desert, and of all persons living in an area 200 miles from the test fell to a Radiological Safety Unit, short-termed Rad-safe. In areas beyond 200 miles the New York operations office of the A.E.C. takes over the responsibility.

Here is the monitoring history of Operation Big Shot, and it is fairly typical. Troops in the field had with them Rad-safe teams, and after the burst, dust, weapons, personnel and the ground, including ground men were checked and radiation levels noted. Paratroopers made their move out of the area just twenty minutes after zero, and were monitored at the planes before climbing aboard for their jumps. At H (zero or burst time) plus twenty minutes, a helicopter entered the vast dust cloud for monitoring purposes. After about an hour, troops were given the signal to advance and enter the blast area. As found out in later interviews, they approached to within 150 yards of ground zero—only two hours after the blast. In the meantime the atomic cloud itself, was receiving radiological attention. Its rate of climb and direction were plotted, and F 84 and T 33 Jets, with samplers on wings, were sent through the radioactive mass to collect dust for later measurement. The tracking of the cloud itself was the task of a special B 29, and as long as the cloud exists as such B 29 monitors trace its journey.

On the ground, the activity of the on-site radiological groups in checking target vicinity, vehicles, and personnel have been mentioned. In addition, off-site groups of Rad-safe check the radiation drop-out at fixed stations and at other points manned with teams brought to the site by plane and truck. All towns within a 200-mile radius are checked.

If warranted an area from 200 to 500 miles from the site is measured by the National Monitoring System. Units are flown by air force C 47 to stations and towns bracketing the cloud, to take samples of dust on gummed paper, or with suction-type collectors.

Beyond the 500-mile area, the National Monitoring System maintains 121 stations, mostly U. S. Weather Bureau posts, to collect continuously dust and rainfall samples, which are sent to the A.E.C. laboratories in New York for activity counts. Keeping tabs on a cloud that is visible is not too difficult, but after the cloud disperses (the April 22

(*Continued on page* 26)

Processing Units and (at right) Brown Control Panelboard for Plexiglas production at Rohm & Haas Company, Bristol, Pa.

CO-OPERATION BIG SHOT

(*Continued from page* 23)

cloud was gone five or six hours after the test) the radioactive dust, in effect, becomes part of the air mass, tracked only by its activity as measured by the monitoring system and plotted on maps. As might be imagined, meteorologists have learned much about mass air movements above the United States from the plots already made of this moving, invisible mass. Radiation levels from the dust have in the past been below 0.1 mr./hr., two days after the blast. Normal background radioactivity varies from 0.01 mr./hr. in New York to 0.05 mr./hr. in Denver.

According to Merril Eisenbud, director of the New York operations office, Health and Safety Division, radioactivity from the cloud is not dangerous and indeed needs extremely sensitive instruments to detect it.

"The radioactivity from atomic weapons tests can be measured with sensitive equipment in exceedingly minute amounts at great distances from the site of detonation," Mr. Eisenbud said. "The amounts observed during past test programs have been so small that many radioactivity measuring instruments would be unable to detect any increase over normal background radiation. . . . .

"Background radioactivity varies geographically to some degree and it also varies hour to hour during the day. During past tests, the average increase in radioactivity across the country was of a magnitude no greater than the ordinary background radioactivity. . . . In isolated instances, higher levels were measured, but in all cases the levels of radiation were far below those considered to be of public health significance."

Long Distance Damage

One of the most fascinating scientific studies used is that of predicting where the blast from the atomic bomb will go, and where it will create damage. Atomic Energy Commission has, at times been surprised at the blast damage bombs do at considerable distances, while closer areas are completely unscathed. During some of the early operations the test shots broke a number of windows in Las Vegas, some 76 miles from the test location, but did no damage to areas between. Why this blast wave should skip in the peculiar way it did, bewildered the A.E.C. and last fall they began experiments to unravel the mystery. Head of the study group is Dr. Everett F. Cox, who is now correlating the vagaries of weather, the blast yield of the bomb, and the peculiarities of sonic waves. Dr. Cox said that in using TNT explosions to check methods of predicting blast waves, instruments were placed at Indian Springs about 45 miles away. Blast strengths ranging from one unit to 3200 units

were recorded from the same size TNT charges, fired at exactly the same time, and in the same place but, five weeks apart. The only difference was the weather.

The reason for the skipping tendencies of the blast is due apparently to temperature inversion in the upper atmosphere. These conditions are fairly common in the morning over desert territory where the air is usually hotter one or two thousand feet above the ground than it is next to the ground. Since sound travels faster in warm air than in cool air, the more rapid travel in the warm air, causes the blast waves to bend downward. As each sound ray hits the ground it is again reflected, and the bending of the sound waves is repeated owing to the inversion pattern. From meteorological studies the scientists are able to predict, to some extent, where the sound and blast damage will concentrate. Focusing of such energy has been responsible for most of the damage at distant points.

For the Nov. 1 test of last year, Dr. Cox said meteorological situations existed in two directions: toward the northwest the sound velocity decreased with altitude and the blast rays were all bent upward. At the same time in the opposite direction, a double-focus situation was found (after the blast was over) to exist. One focus of the blast was about seven miles from the bomb. A second existed about forty miles from the bomb. After one reflection of the focus at forty miles, the blast energy again hit Las Vegas taking out 11 plate glass windows and knocking dishes from shelves. Although the shock wave pressure at Las Vegas was equivalent to a 35-mile wind, window construction was such that it could not withstand the negative pressure wave which occurs after the blast has passed.

As far as predicting where blast damage from a shot will strike, Dr. Cox said there are two main troubles preventing accurate estimation—those of weather and the deficiencies of meteorological instruments. Weather balloons can ascend only 24 miles. However, some of the sound rays are bent back by an air layer which exists 25 to 40 miles above the earth (ozonosphere). It is known, he said, from data collected from V2 rockets, that this is a hot layer of air and is responsible for some of the sound waves heard at great distances.

"During the series of atomic weapon tests conducted here last October and November," Dr. Cox continued, "the residents of St. George, Utah, heard nearly every explosion. Blast waves take longer to travel from the explosion to St. George via the ozonosphere route than they take traveling to St. George via troposphere (surface to 6 miles). From measurements on the length

(*Continued on page 52*)

Mr. and Mrs. Mark C. Hopkins. Mr. Hopkins is coordinator of res. & dev., Pan American Refining Corp.

Mr. and Mrs. Anthony Anable. Mr. Anable is dir., personnel and public relations, The Dorr Co.

Mr. and Mrs. C. L. Baker. Mr. Baker is chem. dir., vice-pres. charge of mfg. and eng., Philadelphia Quartz Co.

ATLANTA MEETING PERSONALITIES

In the April issue we published a report on the recent regional meeting held in Atlanta, Ga.

Space did not permit us to publish all of the pictures we wished to, so—here they are.

Mr. and Mrs. J. E. Ross. Mr. Ross is res. engr., Experimental Station, Georgia Tech.

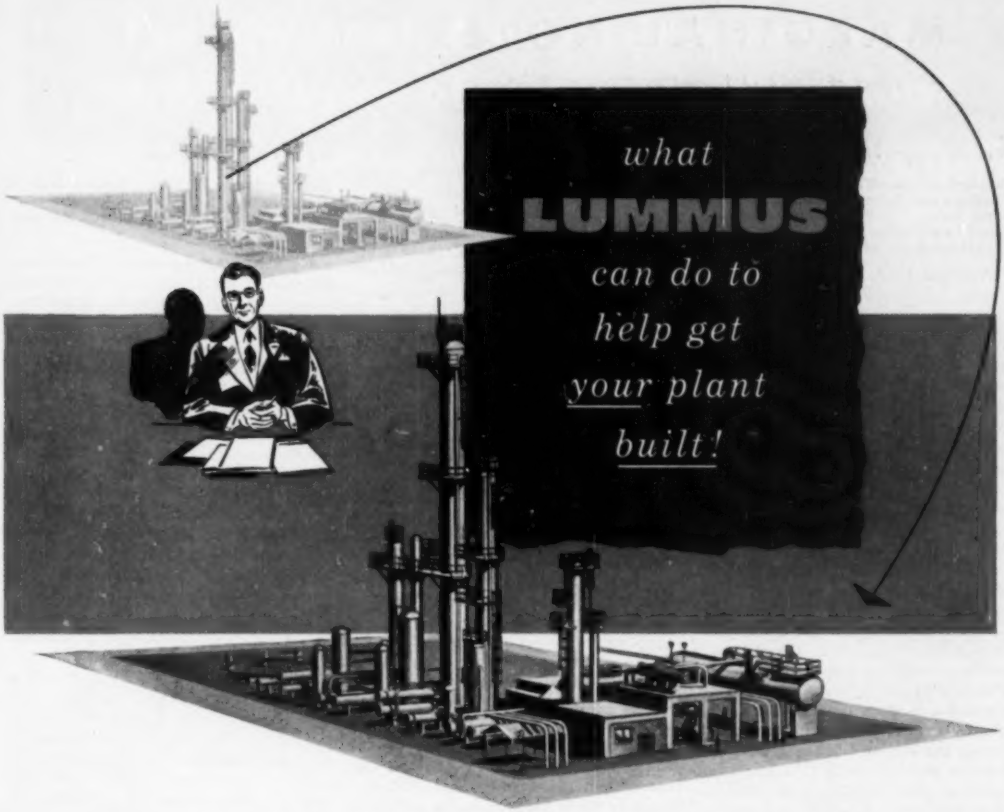
R. S. Rhodes, products dept., Koppers Co., Inc.; G. A. Webb, asst. mgr. dev. sect., Koppers Co., F. W. Adams, Spool Cotton Co.

Asst. prof. M. M. Gilkeson, Jr., Tulane Univ.; B. W. Gamson, dir. res. and dev., Great Lakes Carbon Co.; Brymer, Williams, assoc. prof., dept. of chem. & met. eng., Univ. Mich.

Mr. and Mrs. A. G. Aitchison. Mr. Aitchison is technical dir., Westvaco chem. div., Food Mach. & Chem. Corp.

T. H. Chilton, Past Pres. A.I.Ch.E. and dir. tech. eng. div., Du Pont Co., Inc., with H. E. O'Connell, process design, Ethyl Corp.

Mr. and Mrs. J. W. Mason. Mr. Mason is dean of engineering, Georgia Tech.



Design, engineer and construct it? Of course. These three main classes of service—performed under *one* contract with *single* responsibility—are our bread and butter. They have produced more than 600 plants of all types in just about every country where petroleum is refined or chemicals are made.

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It could work like this. In the interest of "first things first," you may need basic studies and reports covering alternative routes for reaching your goal. If so, rely on Lummus to develop analyses on which to base sound capital investment decisions.

Perhaps your problem is not so much with process units themselves, but with tying the whole system together for full operating efficiency. Lummus has long-established experience in laying out and installing complete off-site facilities—the bringing in of utilities—piping to introduce charge materials and carry off products—tankage, dockage, loading facilities, etc. This is "know-how" you can use to advantage.

Among other added factors are the considerable help we afford in procuring materials, and invaluable counsel in interpreting government rules and regulations—all in all, unique services geared to the times.

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MARGINAL NOTES

News of Books of Interest to Chemical Engineers

Here to Stay—The Punched Card

Punched Cards—Their Applications to Science and Industry. Robert S. Casey and James W. Perry, Editors. Reinhold Publishing Corp., New York. (1951) 506 pp. $10.00.

Reviewed by J. C. Flynn, Chambers Works, Du Pont Co., Wilmington, Del.

PRIOR to 1925 most corporations and agencies utilized conventional manual systems in classifying, summarizing and filing reference and control data. Even large record-keeping groups like the United States Government and life insurance companies had to sort cards, sheets, and reports by hand when attempting to review given types of information found in widely diversified records. Duplicate and even triplicate sets of data were established, each classified in a specified manner to reduce time spent in laboriously reviewing files. Today the great variety and tremendous volume of data rule out the use of such expedients and many record-keeping and finding problems can be solved only by "Punched Cards" systems. It has been said that a modern census, or a Social Security system, could not be attempted without the use of tabulating machines based on punched cards. The novelty of receiving a punched card as a check has long since worn off, a sure sign that the technique has arrived.

Turning to the scientific world, an intolerable condition is rapidly developing or has already developed. As the editors of the book indicate the very bulk of the rapidly expanding mass of scientific and technical information threatens to impair the usefulness of scientific investigation. They state "it has been discovered that considerable improvement in speed and ease of locating information in files can be achieved by using punched cards. . . . Another purpose is to record present knowledge and experience so that better use of the presently available punched-card devices, and desired devices better suited to practical needs, will be stimulated." The book has fulfilled these purposes for it should provide an avenue of escape for those scientists and engineers who find themselves trapped by the volume of technical information which they are trying to utilize.

The book contains 28 articles, three dealing with the basic principles of punched cards, 10 with advanced principles and techniques, 14 with specific case histories, and one with future possibilities. The articles are presented by 32 contributors some of whom jointly sponsored a particular article.

The early chapters of the book, describing nine "Punched Hole" sorting systems and explaining the basic principles of hand-sorted punched cards, are the strongest part of the presentation. The discussion on coding problems is also helpful as it highlights categories of material that can be coded and the problems encountered in establishing a simple yet comprehensive code system. The treatment of hand-posted punched-card systems is thorough and well covered. The presentation of machine-posted systems is sketchy and incomplete.

The case histories of punched-card applications are confined mainly to examples where solutions have been found to "the rapidly expanding mass of scientific and technical information."

The thoroughness of the editors in attempting to present an advanced as well as simple treatise of the subject is shown in Part III, General and Fundamental Considerations. Herein, ten advanced discussions are presented which can have utility only where an organization is attempting to go beyond the basic use of the card systems. The articles in this section are highly technical and may serve as a good reference source but certainly are not applicable for the use of the average reader.

The extensive bibliography lends an air of authenticity and is evidence that the editors are chemists and scientists, since it contains no less than 276 references.

In general, the book fulfills a real need as it presents the basic fundamentals of punched-card systems and illustrates them clearly by describing various systems that can be used for recording and classifying scientific data. The field is in great need of new and improved controls and this book should stimulate the imagination to see the future of both manual and mechanical punched-card applications. The editors' efforts will be useful to engineers, chemists, scientists and librarians.

The material in the book, aside from the basic-principle presentations, is not too well organized. There seems to be little continuity and it would appear that the authors could have been more selective in the titles and subjects discussed after the basic principles were presented.

It's a Fair Exchange

Ion Exchange Resins. Robert Kunin and Robert J. Myers. John Wiley & Sons, Inc., New York (1950). 212 pp. $4.75.

Reviewed by Theodore Vermeulen, Professor of Chemical Engineering, University of California, Berkeley, Calif.

THIS recent book provides a short informative description of the properties and performance of ion exchange materials. It is written to arouse the interest of a newcomer to the field of ion exchange, and to acquaint him with its widespread potentialities as these are reflected in the reference literature.

At the start, the theories of what ion exchange is, and how and why it occurs, are reviewed in historical sequence. Equilibrium and kinetic data are presented for illustrative systems, with useful emphasis on the relative replacing power of different ions. The synthesis is described sparingly in terms of a few laboratory-scale reactions, together with typical polymerization equations. The capacity, density, and chemical type of several commercially available resins are tabulated for convenient reference.

Methods of application are then reviewed, which stress the principles of column operation and include a short discussion of chromatographic fractionation. Two chapters follow on water softening, or replacement of calcium and magnesium ions by sodium ions, and on water deionization by cation and anion exchange in combination. These operations are elaborated effectively by graphs of numerical performance data from the Rohm & Haas laboratories.

Numerous analytical, pharmaceutical, and other applications are mentioned, although not with the same thoroughness as in Nachod's book on ion exchange. Laboratory procedures are then given for characterizing ion exchange resins according to their particle size range, density, attrition rate, and exchange capacity.

The last chapter deals with the design of ion exchange units. Arithmetic scale-up of laboratory data is explained for cases of water softening, deionization, and metal recovery. Cost-estimation data assembled by Monet are reported, and the construction features of industrial-scale column equipment are reviewed.

(*Continued on page 56*)

Chemical Engineering Progress

DATA SERVICE

BULLETINS

1 • *SPRAY NOZZLE.* A technical bulletin on type T for tangential spray nozzles from Spray Engineering Co. The bulletin gives data on standard-angle and wide-angle nozzles. Gives numbers, pipe sizes, etc., as well as capacity in gallons for various pressures. Covers sizes of nozzles of increased capacity which are completely new with the company.

2 • *PLASTIC PRESSES.* The Hydraulic Press Mfg. Co. has a 16-page two-color catalog covering its line of 9-, 16-, 32- and 60-oz. hydraulic plastics injection molding machines. Gives specifications for every model. Shows photographs of parts typical of those being molded.

3 • *DUST CONTROL.* Pangborn Corp. with a new 28-page bulletin on the control of industrial dust. Covers CH system which utilizes cloth-type filters for collecting finely divided dry dust. Bulletin well illustrated showing use, installation, screen rapping mechanism, as well as a table showing how to select a dust collector for a particular type of dust.

4 • *STEAM GENERATOR.* A bulletin on the unit steam generator of Preferred Utilities Mfg. Corp. Describes the component features of the self-contained unit—either gas- or oil-fired unit and well-illustrated three-dimensional-cutaway views show construction details such as staggered tubes, four-pass gas travel, induced draft, etc.

5 • *STEAM TRAPS.* A description of steam traps equipped with bronze, Monel, or stainless, with bodies in bronze, semisteel or cast steel in sizes of 1/4 to 2 in. for all pressures from vacuum to 300 lbs. From W. H. Nicholson & Co. Gives capacity tables, dimensions, recommended piping diagrams, typical applications, etc.

6 • 7 • *HYDROGEN, OXYGEN AND AMMONIA.* General Industrial Development Corp. has two folders from the Bamag-Meguin A. G. (6) on an electrolyzer for producing hydrogen and oxygen. Keyed to an industrial production the unit is illustrated showing installation in plants, produces extremely pure gas. Construction details are shown. Also has a description of the electrolyzer shell. Units range from 40 to 400 cu.m. H/hr., Amperages range from 2250 at 90 v. to 5600 at 360 volts for the minimum and maximum capacities. (7) is a description of the Bamag plants for making ammonia synthetically. Covers the catalytic oxidation of ammonia to form nitric acid with a platinum-rhodium catalyst; a concentrating plant for making nitric acid of 50 to 98% by sulfuric acid absorption of the water, oxidation of ammonia gas; sodium nitrate plant, ammonium nitrate plant, etc.

8 • *CENTRIFUGALS.* To celebrate the 100th year of its business, Tolhurst Centrifugals, a division of American Machine & Metals, Inc., has published a booklet tracing the development of centrifugal machinery from 1852 to the present. Illustrated with equipment showing the progress over the years.

9 • *HUMIDITY CONTROLLER.* A bulletin from Surface Combustion Corp. on Kathabar humidity conditioning equipment. A collection of ads which has appeared in some technical books. It is used in the chemical, pharmaceutical and other industries. Uses a hydroscopic solution to absorb water.

10 • *CORROSION-RESISTANT VALVES.* A publication from the Rockwell Mfg. Co. describing Nordstrom valves of corrosion-resistant type. In color shows the principle of the valve, the basic design of the unit and illustrations showing application. Corrosion chart shows the metal and lubricant recommendations for a number of standard chemicals. Latter part of book is a catalog of the types giving specifications, prices, etc.

11 • *FEEDER CONVEYORS.* Link-Belt Co. booklet on Bulk-Flo conveyors and elevators. For chemical handling of flowable materials such as coal, lime, totally enclosed dust type. Booklet shows installations, specifications, plus engineering design data on proper selection.

12 • *COMBINATION STILL.* An extensive bulletin on a new type of still termed Stilcok from the Stilcok Co. For use on coals, lignites, wood, oils, etc., for recovery of water, oil, gases and residues. Company claims a new principle in which the method

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of heat application is inside the material to be distilled and not on the outside. Blueprints, drawings, and a large amount of technical detail on the features of the still.

14 • STEEL VALVES. A general data book on designs and materials of the Brown Valve Co. Covers globe valves, swings, checks, angles, slide, etc. Gives specifications, construction details, price, sizes.

15 • MIXERS AND FEEDERS. Infilco Inc. with a new bulletin on its chemical mixers and feeders for the process industries. Combines in one continuous automatic process the preparation of chemical solutions and the volumetric feeding of the prepared materials through orifices operating under a constant head. Can be equipped with a manual feed rate adjuster, automatic proportioner. Gives dimensions and capacities and describes the action of the plow-shaped agitators which are revolved in vertical planes to give a uniform mixing action through the whole of the tank.

16 • FILMSTRIP ON PUMPS. Available from Allis-Chalmers Mfg. Co. is a group of three 35 mm. sound filmstrips on centrifugal pumps. Booklets are also available describing the filmstrips and showing pictures of what will be shown. Titles are—"How and Why of Centrifugal Pumps," describing the operations, "Pump Maintenance" and "Covering All the Angles," which describe the proper way to select a pump.

17 • INFRARED ANALYSIS. An 8-page booklet describing how infrared analysis has been applied by eight different manufacturers to product control. The bulletin is from Perkin-Elmer Corp. and covers case histories from Merck, Du Pont, Hooker, Smith, Kline & French, and others. Problems include detection of water in freon, penicillin G. assay, quality control of inks, assay of drugs, and plant production control.

18 • PNEUMATIC BULK HANDLING. A technical information and data booklet on handling of bulk materials by pneumatic conveyors. From the Dracco Corp. This well-illustrated booklet covers the industries in which it is applicable, chemicals being one of them, the reasons for the efficiency of air stream carrying, as well as illustrations of constructions, types, accessories, pumps, motors, discharge locks, etc.

19 • NICKEL PLATING. A technical bulletin of complete and varied information from the International Nickel Co., Inc., on how to nickel plate. A book of practical recommendations and descriptions. It also contains a keyed bibliography of additional sources of information. Information on properties of deposits, plating conditions, solutions, recognition of difficulties, etc.

EQUIPMENT

22 • REGULATING VALVES. A new class of regulating valves with double-seated diaphragms made by the Leslie Co. Features a contoured body for flow line, ISA standard face-to-face dimensions. Stellited seating surfaces and renewable self-aligning guides.

23 • SCREW PUMP. A new external gear and bearing bracket type screw pump for positive displacement of nonlubricating liquids is being produced by the Sier-Bath Gear & Pump Co., Inc. For liquids of all viscosities from 1 to 700 gals./min. Features single-point alignment. Available in horizontal and vertical construction, corrosion-resistant alloys, steam-jacketed bodies, special stuffing boxes, etc.

24 • VISCOMETERS. For recording or recording-controlling of viscosity in industrial plants, Norcross Corp. has a control model which measures, records, and where desirable can control viscosity solutions of from 1 to 200,000 cps. Bulletin available shows operation, design of the measuring element, principle of operation of the measuring element, charts, etc.

25 • RETICLES. For precision optical measuring, United States Testing Co., Inc., offers through its instruments division, super-precision reticles. For use on microscopes, collimators, micro-balances, comparators and other measuring instruments. The reticles are scales, step-wedged, protractor, black and white check, ruled circles or angular.

26 • LEAK DETECTOR. For the chemical plant with underground pipes and the problem of checking leaks in water or low viscosity fuel lines, the Goldak Co. has a combination

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leak detector pipe locator. Electronic in principle the unit may be carried and operated by one man. Can also be used to detect leaks in steam and air pipes, to follow underground drill bits.

27 • AFTER COOLER. For the after cooling of compressed air or gases Niagara Blower Co. has a newly designed aero after cooler with a capacity increase of from 25% to 75% over previous models. Cooling is done by evaporation and recirculating water sprays on the surface of tubes. Improved capacity has been gained by more efficient distribution of compressed gas.

28 • CENTRIFUGAL PUMPS. Ingersoll-Rand Co. with newly designed small, single-stage double-suction pumps. 3-, 4-, 5-, and 6-in. sizes, the pumps have double mechanical shaft seals and ball bearings. For general hydraulic services at temperatures up to 200° F., capacities of 2100 gals./min. and pressures up to 150 lbs./sq.in.

29 • RADIOACTIVE MONITOR. Ohmart Corp. has a new cell for precision measurement of gamma radiation. Cell converts radioactive energy into electrical energy which is hooked to a high impedance current recorder. For continuous monitoring of radiation in health physics work or industrial processes where gamma ray activity is present. Gives a continuous record of radioactive dosages.

30 • INSULATED VAT. An insulated vat with a stainless lining for mixing and storing liquids such as milk, syrups, emulsions, pharmaceutical products, beverages, etc., is now being made by Cherry-Burrell Corp. Eleven standard sizes ranging from 100 to 1000 gals. Two inches of corkboard insulation sump-type outlet with sanitary valve, stainless steel agitator, removable for cleaning. Welded steel construction.

31 • PORTABLE MIXER. A portable mixer which uses a flexible shaft connected to a separate motor, is a new development of Process Industries Engineers, Inc. By removing the motor from the propeller shaft, the weight of the mixer is reduced. Two models—a propeller shaft 5/8 in. in diam. and 7/8 in. in diam. Can use motors from 1/4 to 3 hp. giving revolutions per minute from 520 to 3450. Flexible shaft nominally 96 in. long. Motor can be attached to the side of mixing vessels on pedestals, hung overhead, or placed on a portable pushtruck. Various alloys and constructions. Through the use of a vapor-tight gasket, motors can be placed in an offroom location where inflammable or explosive liquids are being mixed.

32 • PRESSURE TRANSMITTER. From Wright Engineering Co. the Digitran for transmitting pressures from 0 to 3 lbs./sq.in. abs. to 5000 lbs./sq.in. abs. Uses magnetic field vibrating wire principle and has been developed to service digital computers, automatic process control and digital recording systems. Can be had with or without a temperature control for variations of temperatures.

33 • HIGH TEMPERATURE FURNACE. A furnace for 2200° F. operation using nonoxidizing alloy elements and built in various sizes, is available from K. H. Huppert Co. For use in firing ceramics or other high temperature operations.

34 • CENTRIFUGALS. Heyl & Patterson, Inc., are now agents for the Reineveld centrifugals made in Holland. Standard sizes, have drums from 36 to 80 in. in diam. with centrifugal forces up to 1500 gravity. Main bearing is centrally located. Manufacturer claims improved filter bed. Also a totally enclosed vapor-type design for dangerous materials.

35 • MULLERS. Two new high capacity National Engineering Co. mixmullers available. Have greater mulling pressure. Have adjustable spring pressures up to 4000 lbs. Large discharge door plus a borium carbide wearing edge of plow. Bulletin available which describes the new features.

36 • CENTER-SLUNG CENTRIFUGAL. For the chemical and process industries Tolhurst Centrifugals, a division of American Machine & Metals, Inc., with a new center-slung centrifugal. Can handle unbalanced loads from three to four times greater than previous models. Features spindle mounted in roller, double row of ball bearings in a tubular housing, faster drainage, self-energizing brake, etc. Basket sizes 12 in. through 108-in. diam.

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37 • VACUUM DISC VALVES. F. J. Stokes Machine Co. has designed a new handwheel disc valve for high vacuum service. Sizes from 6 in. through 16 in. Features low flow resistance, a disc which rotates 90°, can be operated with vacuum on either side, opened and closed by one gear in a few seconds. Bulletin available.

38 • INJECTOR PUMP. A high pressure chemical injector pump developed by Texsteam Corp. A 50-lb. feed pressure of air, gas, water or steam will give up to 20,000 lbs. discharge pressure. Feed pressure is adjusted from 5 to 50 lbs. to give desired outlet pressure of 100 up through 20,000 lbs. Delivers ½ pt. to 360 gals./day. Stellite pistons. Mechanical parts operate in an oil bath sealed against dust. For handling chemicals, hydraulic fluids, testing valves, pressure vessels, etc.

39 • WOOD-LINED PIPE. A smooth wood lining for steel pipe is featured by Michigan Pipe Co. Designed especially for corrosive liquids, slurries, fumes, gases, etc. Combines low frictional resistance with high flow capacity, prevents slime build-up and corrosion attack. For pressures up to 250 lbs./sq.in. and temperatures up to 180° F. Available in standard lengths of 10, 20 ft. or in tailor-made lengths for specific requirements. Internal diameters from 4 in. through 36 in. For chemical processing industries carrying waste liquor lines, process water line service, acid, alkali and saline solutions, etc.

CHEMICALS

42 • LITHIUM STEARATE. A technical service report from Witco Chemical Co. on the use of lithium stearate for the grease industry. Typical properties of the product, performance of various base oils, and effect on the rate of penetration.

43 • ORGANIC PRICE LIST. A catalog from Eastern Chemical Corp. on prices of organic chemicals for laboratories. Covers more than 1000 chemicals. Gives also, in most cases, melting or boiling points.

44 • LACQUER SPECIFICATION. A guide to specification lacquers for finishing military items has been printed by Hercules Powder Co. Leaflet gives type of lacquer finishing material called for plus permissible or appropriate specification numbers grouped according to use.

45 • PLASTICIZER. From Monsanto Chemical Co. a technical bulletin on Santicizer 3 a sulfonamide-type plasticizer for heat-sensitive adhesives and lacquers such as nitro cellulose, polyvinyl acetate, zein coatings, etc.

46 • DIMETHYLETHANOLAMINE. An industrial grade of dimethylethanolamine is in production by Carbide & Carbon Chemicals Co. For use by manufacturers of ion exchange resins, wetting agents, textile assistants, etc., the concentrated amine is available as a 70% solution. Pharmaceutical grade also available.

47 • MORPHOLINE. For formulation of water-resistant waxes and polishes, for control of alkalinity in boilers and steam lines, Dow Chemical Co. is now producing Morpholine. The ring compound contains both an amine and an ether group.

48 • ORGANIC CHLORINE COMPOUNDS. A new booklet covering a family of organic chlorine compounds has been published by Carbide & Carbon Chemicals Co. Describes 11 organic chlorine compounds sold in commercial quantities. Gives uses, physical properties, specifications, shipping data. Also gives description of laboratory tests recommended for determining specifications.

49 • COATING CATALYST. Advance Solvents & Chemical Corp. has introduced a rare earth naphthenate as a catalyst to promote cross-linking polymerization at elevated temperatures in coatings. For use as a drier catalyst in baked finishes based on urea-formaldehyde, melamine or alkyd resins. This rare earth naphthenate increases the molecular cross-linking of heat-reactive resins resulting in increased hardness of the film.

50 • PENTACHLOROPHENOL. A booklet on pentachlorophenol used to protect wood against decay and insect attack, by Monsanto Chemical Co. Answers 51 questions commonly asked by those interested in preserving wood.

51 • PERFUME INGREDIENT. A new nameless compound 77-B from Tennessee Eastman Corp. has a perfume ingredient. Quinoline-like in odor. Technical data sheet is available which gives physical properties.

52 • POLYESTER RESINS. A 30-page booklet by Bakelite Co. on polyester resins. Data of interest to designers, the booklet summarizes properties of each different resin. Gives range of physical properties, electrical properties, chemical resistance, casting properties, etc.

53 • DYE PENETRANT. For high-speed inspection processes a dye penetrant from Turco Products, Inc. Dye will penetrate smallest defect on a metal surface. For both ferrous and nonferrous metals.

54 • CARBON BLACK. A new grade of rubber reinforcing oil furnace black to give a 15-25% increased tire mileage is announced by Godfrey L. Cabot, Inc. Has increased reinforcing ability and company recommends it for high tensile, high abrasion resistant materials.

55 • "WHAT'S A SILICONE?" An information bulletin from Dow Corning Corp. on the properties of a silicone, plus its application to numerous industries. Written in a free, nontechnical style, the book will nevertheless bring home the varied applications of the material.

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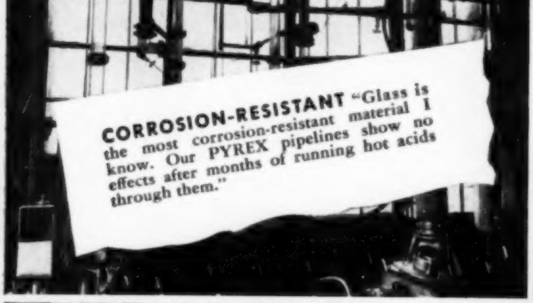

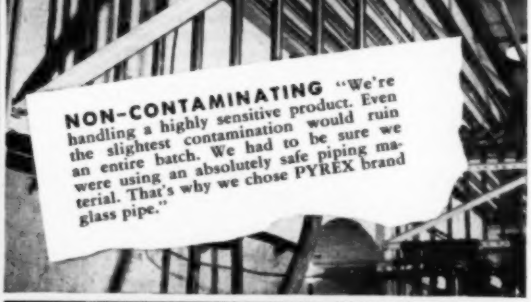

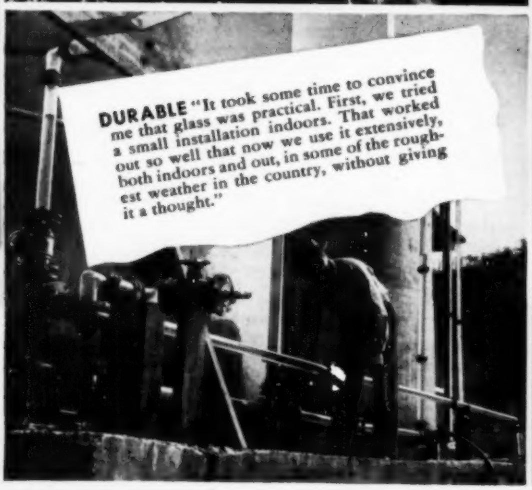

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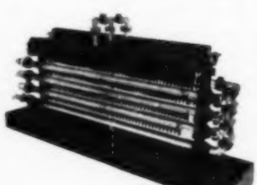

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MANPOWER—ONLY PART OF THE PROBLEM

DR. CORNELIS W. deKIEWIET

President, University of Rochester, Rochester, New York

TODAY one question holds an acute interest for me—and this is the manpower question, the problem of producing high level skills. It is a profoundly difficult crisis that all great industries, professions, and callings are facing in modern America. There simply are not enough people of high level skill, in the engineering profession or in other comparable callings, to go around. As a background for the concern of the supply of manpower, I would call attention to some aspects of the modern world. Our preoccupation with immediate problems is such that sometimes we neglect to bring a focus to bear upon the wider, more inclusive international, world background, with which our lives are concerned.

There is going on in the modern world a series of immense changes. We have at the present moment, an acute and painful interest about our relations with certain powers of the world, and with one great power in particular. That focus is so sharp that it obscures other changes that are taking place in other parts of the world; changes that are going to upset what you are doing, what I am doing, what we all are doing. There is going on what I call a colonial revolution. A revolution, in the profess of which, a number of areas which we have called imperial areas, colonial areas, dependent areas are detaching themselves from their metropolitan powers; whether they are detaching themselves, as Iran is doing violently at the present moment from the industrial and economic bondage of Great Britain, or detaching themselves politically as India has done. Now, all of those areas, sooner or later, will try to equip themselves with the amenities of modern science and technology. There is impending, therefore, a still greater call upon the skills of the world than already exists, and we know how acute and demanding that call is at the present moment. So the crisis in manpower, in my judgment, is going to become greater; and become a world-wide rather than simply an American crisis.

There is a further portent in this colonial revolution. Ours is a nation of free industrial enterprise. Do you know, and have you considered, that in most areas of the world that either is not true or cannot logically be true. We have noticed in Great Britain, for instance, under the regime of socialism, a departure from the system of the kind of industrial production which obtains in this country. I intend no unnecessary critical comments, but am trying to describe objectively a world trend that ultimately is going to involve us all. In these politically new, emerging, societies, such as Iran or India or China or the former Netherlands East Indies, Malaya, Burma, and others—equipment and tooling for industrial enterprise is also bound to evolve. And there will inevitably be a pattern in which the financing, the organization, ultimately the fundamental disposition is going to be governmental in policy. I can forsee a day not too far removed, when those ideals that we take for granted—those methods of perception, those types of procedure we know are and can be greatly successful—shall stand in the isolated world, an island of special economic significance. To maintain that integrity of principles we shall have to be even more successful in what we are doing than we are now. We shall have to maintain, first of all, a steady supply of the highest skills, flowing easily and being readily accepted in American industry. That is the engineer's business.

I would like to call attention to an even more urgent fundamental than the present preoccupation with manpower, and that is the basic knowledge upon which industrial technology has to draw. If I were to ask which is the greatest scientific country in our modern world, you probably would say, the United States of America. In one sense that would be correct. There is no other spot in the modern world where there are so many scientists of worth. Yet, the extraordinary power of engineers in applying scientific knowledge—in turning it into an instrument, or a process, or a commodity, or a facility, or an amenity—is making such demand upon science, that the concern about the shortage of professional people, is also the concern of those responsible for the supervision of great institutions in which scientists are produced. There is already a shortage of scientists, those research people who provide the basic data that engineers use. There is developing, in this country, a shortage of science.

There was a time when the body of knowledge in science, physics, chemistry particularly, was such that there was a lag between the application of science and the production of science. That lag is shortening. The very crisis in which we are involved at this moment when we need new weapons, new approaches, new answers to challenges is causing us to turn more and more to science to find ideas and to give them execution. This country is not paying sufficient attention to the production of fundamental scientists and to the expansion and production of a greater body of fundamental scientific principles.

There is not anything in my judgment that throws a clearer light upon the obtuseness in vision, in Washington, than the failure to support the National Science Foundation. I do not think myself, in spite of some of the magnificent steps that have been taken by American industry, that American industrial leaders are sufficiently aware of the interdependence of industry upon the training of scientists upon the production of greatly increasing scientific knowledge. This is an important obligation—an obligation which engineers also, who have so much of the destiny of the nation in their hands, should feel is theirs to discharge by practically and otherwise supporting the training of scientists and the production of scientific knowledge.

The genius of American industry is rooted in a system of a broad general education; of respect, if you please, for the dignity of man, for the capabilities that lie within man actually or potentially. The force that education contributes emerges in the great activities, in great concerns, in the production of more science and scientific knowledge, in the production of a more humane set of relations between those of us who work together, and it is the responsibility of all of the great agencies of American society—whether governmental or industrial in character—to pay particular attention to those institutions where high level skill is trained for American society. I am unashamedly making a plea for the great American university, which is in danger of lagging behind for want of adequate understanding and support in carrying out its responsibilities.

The problem of manpower is greater than the problem of war itself. For, bad as war may be, it is, so far, an interlude, dramatic, catastrophic, in our society. But the application of science to technology, the bridges that you build between the things that are known and the things that are used, goes on eternally. That is something that will go on as long as men as we know them exist.

CANDIDATES FOR MEMBERSHIP IN A. I. Ch. E.

The following is a list of candidates for the designated grades of membership in A.I.Ch.E. recommended for election by the Committee on Admissions.

These names are listed in accordance with Article III, Section 7, of the Constitution of A.I.Ch.E.

Objections to the election of any of these candidates from Active Members will receive careful consideration if received before June 15, 1952, at the Office of the Secretary, A.I.Ch.E., 120 East 41st, New York 17.

APPLICANTS FOR ACTIVE MEMBERSHIP

Alves, George E., *New Castle, Del.*
Anderson, Frank L., *Texas City, Tex.*
Atkins, Chas. W., *Charleston, W. Va.*
Baker, Harold H., Jr., *Akron, Ohio*
Barrett, Robert C., *Cartersville, Ga.*
Birkicht, E. R., *Rochester, N. Y.*
Bowen, Frank W., *Toledo, Ohio*
Burtis, Theodore A., *Marcus Hook, Pa.*
Cadogan William P., *Cincinnati, Ohio*
Carpenter, John S., *Concord, Calif.*
Coleman, George W., *Los Angeles, Calif.*
Collard, C. Norman, *Wayland, Mass.*
Crandall, A. Ralph, *Borger, Tex.*
Dorsey, John J., Jr., *Monroe, La.*
Doub, John J., *Tonawanda, N. Y.*
Drake, Edward, *Niagara Falls, N. Y.*
Gaines, T. H., Jr., *Venice, Calif.*
Gregory, J. Robt., *Charleston, W. Va.*
Hall, Donald D., *Midland, Mich.*
Harrington, Edwin W., *Akron, Ohio*
Harvey, Edward D., *Wilmington, Del.*
Kuehl, Carl A., *Midland, Mich.*
Lambert, Benj. A., *Hanover, Mass.*
Locker, H. V., *Aruba, N. W. I.*
Martinez, Boni Philip, *Baltimore, Md.*
McCulloch, Charles E., *New York, N. Y.*
Motl, C. Woolsey, *Wyoming, Ohio*
Mugele, Raymond A., *Emeryville, Calif.*
Putnam, Wallace J., *Charleston, W. Va.*
Reynolds, Randall S., *Cuyahoga Falls, Ohio*
Smith, Clifford W., *So. Charleston, W. Va.*
Tielrooy, Jack, *Fullerton, Calif.*
Walsh, Edward J., *Baltimore, Md.*
Wright, Roy E., *Berkeley, Calif.*

APPLICANTS FOR ASSOCIATE MEMBERSHIP

Davis, Elbert L., *Tuscaloosa, Ala.*
Dees, A. Clarence, *Cushing, Okla.*
Follows, Alan G., *Syracuse, N. Y.*
Hudson, Thomas B., Jr., *Pittsburgh, Pa.*
Martini, E., *Stamford, Conn.*
Nauman, E. F., *Houston, Tex.*
Shaw, Clifford, *Dallas, Tex.*

APPLICANTS FOR JUNIOR MEMBERSHIP

Acosta C., Jesus, *Xicotencatl, Tamps., Mexico*
Altman, Manfred, *Richland, Wash.*
Ansara, James T., *Waltham, Mass.*
Arango, Claudino, *Linden, N. J.*
Babcock, Alfred B., Jr., *Dobbs Ferry, N. Y.*
Baird, Raymond K., *Los Angeles, Calif.*
Berdan, John V. H., *Drexel Hill, Pa.*
Bryan, H. B., *Webster Groves, Mo.*
Burrell, William A., *Spartanburg, S. C.*
Carrow, John W., III, *Wilmington, Del.*
Chesworth, Robert H., *Richland, Wash.*
Chien, Luther C., *Pitman, N. J.*
Clark, Charles H., *Crystal Lake, Ill.*
Connelly, Frank J., Jr., *South Amboy, N. J.*
Dallman, William A., *Springfield, Mass.*
Densmore, Robert E., Jr., *Pasadena, Calif.*
Dieterich, Melvin L., *Westlake, Ohio*
Doyle, George W., *Edgewood, Md.*
Ferron, William O., *Wyandotte, Mich.*
Field, Joseph H., *Bruceton, Pa.*
Finger, Burton J., *Bronx, N. Y.*

(*Continued on page 44*)

Secretary's Report

S. L. TYLER

THE matters to come before the Executive Committee in the month of April were of such a nature that the meeting was held by mail. The result of the mail ballot was as follows:

The Minutes of the previous meeting were approved as issued; bills for the month were approved for payment. Those whose names were listed in the March, 1952, issue of "C.E.P." as candidates for membership, approved by the Committee on Admissions, were with one exception elected to the grades of membership as indicated; this one case is being held because of comment from the membership for further consideration by the Committee on Admissions. In addition to those listed in "C.E.P." there were 114 Student members elected, which brings the total to 1,826.

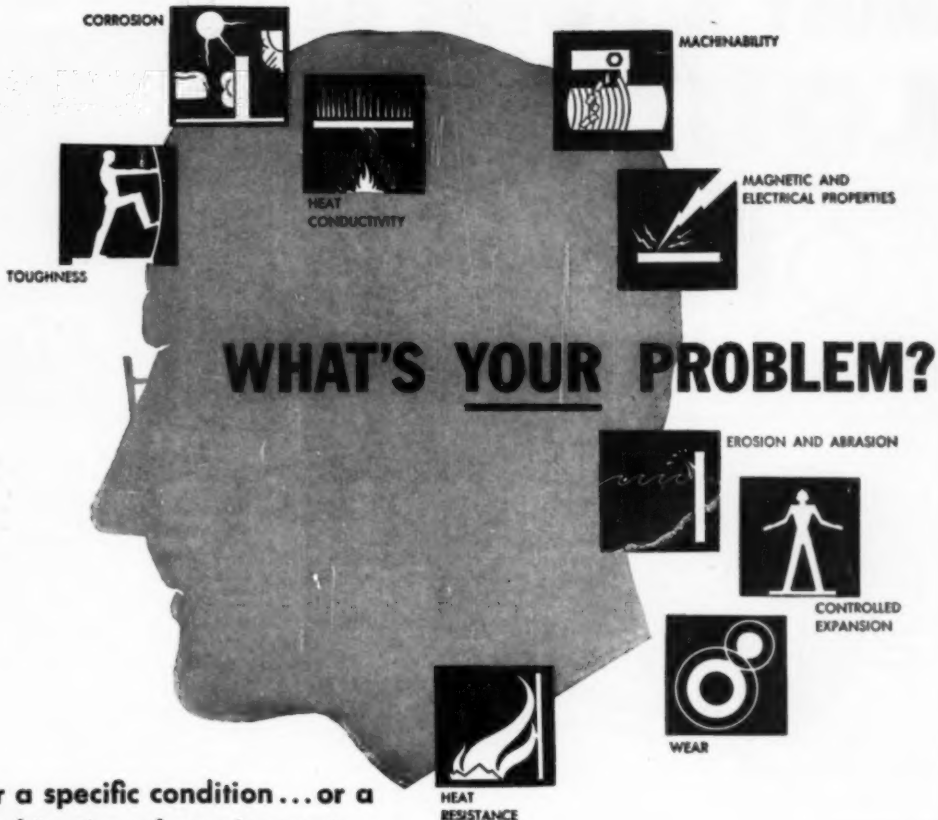
James G. Knudsen was appointed a vice-chairman of the Membership Committee and B. J. Ferro an additional member of that Committee. Four resignations from membership were received and accepted. Two Junior members, namely, A. E. Austin and B. F. Schrader, reported that they had entered the Armed Forces, and their names were placed on the Suspense List.

F. J. Van Antwerpen was appointed as official Institute representative at the inauguration of L. W. Jones as president of the State University of New Jersey.

CANDIDATES

(*Continued from page 42*)

Franson, Paul D., *Chicago, Ill.*
Fullerton, Charles P., *Texas City, Tex.*
Gerttula, V. Gordon, *Camas, Wash.*
Greenstein, Robert I., *Forest Hills, N. Y.*
Gutai, John A., Jr., *Boston, Mass.*
Handwerk, Glenn E., *Tulsa, Okla.*
Hardwicke, Norman L., *Texas City, Tex.*
Henry, William L., Jr., *Birmingham, Ala.*
Hertzog, Richard R., *Anniston, Ala.*
Heslin, Edward P., *New Haven, Conn.*
Hildebrand, Arthur S., *New York.*
Hinkle, J. R., *Corpus Christi, Tex.*
Hofto, John R., *So. Charleston, W. Va.*
Hutchins, James R., *Sunbury, Pa.*
Jape, Francis, *Richland, Wash.*
Johnson, Donald L., *Birmingham, Mich.*
Katz, Irving, *Madison, Wis.*
Klaphaak, Peter J., *Riverside, Ill.*
Klaus, Carl G., *St. Paul, Minn.*
Knowles, Carlton G., *St. Albans, W. Va.*
Kron, Carl M., *Borger, Tex.*
Lake, William C., *Tulsa, Okla.*
Lang, Edward George, *Houston, Tex.*
Lashmet, Peter Kerns, *Ann Arbor, Mich.*
Laundrie, Robert W., *Akron, Ohio*
Lection, Frank J., *Springfield, Mass.*
Lee, Paul L., *Kingsport, Tenn.*
MacDermott, C. P., *Charleston, W. Va.*
MacKinnon, Aleck M., *Norwood, Pa.*
Marshall, Thomas, III, *Wilmington, Del.*
Matulis, Joseph T., *Lawrence, Kan.*
Monteleone, Frank J., Jr., *New Orleans, La.*
Morgan, Robert M., *Charleston, W. Va.*
Morss, Henry B., *Whittier, Calif.*
Oehler, Harris A., *Texas City, Tex.*
Parnes, Murray Leonard, *New York.*
Pauls, Roger N., *Steubenville, Ohio*
Peters, Henry F., *New York, N. Y.*
Prabhkar, R., *Gary, Ind.*
Rose, G. A., *Charleston, W. Va.*
Rothrock, Robert S., Jr., *Wilmington, Del.*
Runes, Eugene, *Baltimore, Md.*
Salmon, Merlyn L., *Denver, Col.*
Saunders, George W., *Avon Lake, Ohio*
Schaefer, Frank A., *Philadelphia, Pa.*
Schmidt, Wallace B., *West Hempstead, N. Y.*
Shoaf, Joseph, *Golden, Col.*
Stokes, John D., *Clifton, N. J.*
Sundback, Raymond A., *Jersey City, N. J.*
Sutor, Walter L., *Wilmington, Del.*
Taub, Stephen E., *Brooklyn, N. Y.*
Thomas, R. Keith, Jr., *St. Louis, Mo.*
Todd, David B., *Berkeley, Calif.*
Valentine, David C, *Hammond, Ind.*
Watts, Herbert L., *Pine Bluff Arsenal, Ark.*
Weinberger, Monroe A., *Wilmington, Del.*
Wexler, Jack, *Moorestown, N. J.*
Wilansky, Harold, *Corning, N. Y.*
Willard, T. L., *Akron, Ohio*
Wilmot, Duane E., *Whiting, Ind.*



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Name.. Title........................

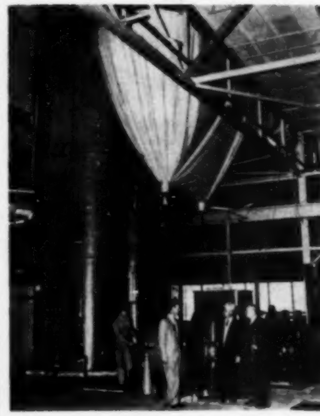
Company..

Address..

City.. State........................

THE INTERNATIONAL NICKEL COMPANY, INC. 67 WALL STREET NEW YORK 5, N. Y.

NEW OXYGEN PLANT



A new oxygen plant was opened last month in Houston, Tex., by the Houston Oxygen Co. The plant will make liquid and gaseous oxygen and nitrogen as well as gaseous argon. Above are shown the expansion engine and generator, at the extreme left is the base of the rectifying column, and next to it the cold dryer. The bag at top is the crude argon balloon. Picture taken at opening of the plant shows (right to left) A. Herzstein, general manager, O. L. Rogers, sales manager, and Alfred K. Smith, president.

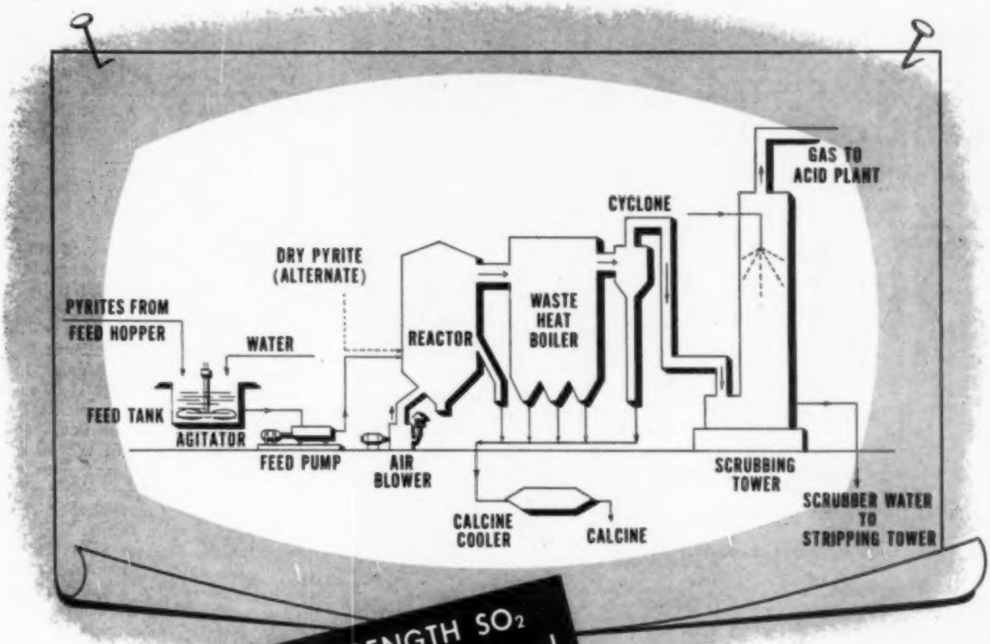
SPENCER TO BUILD NITRIC UNITS

Spencer Chemical Co. has completed plans for the installation of two additional nitric acid units at their Jayhawk Works, and two auxiliary storage spheres at the Henderson Works, at a total cost of approximately $1,850,000. This information was released by K. A. Spencer, president of the Company, in his quarterly report to stockholders. He said that this will permit the company to increase substantially its production of fertilizer grade ammonium nitrate, and will also materially reduce the company's dependence on the leased facilities at the Charlestown Works. The new installations are expected to be completed and in operation by June, 1953.

HOOKER SPONSORS CH.E. FELLOWSHIP

Hooker Electrochemical Co. is sponsoring a research fellowship in chemical engineering at the University of Washington. While no specific assignment has been made, the research will be concerned with uses of caustic soda and chlorine as related to the use of waste products of the pulp industry such as lignin.

(*More News on page* 48)


GAS TO
ACID PLANT
CYCLONE
DRY PYRITE
(ALTERNATE)
WASTE
HEAT
BOILER
PYRITES FROM
FEED HOPPER
WATER
REACTOR
FEED TANK
AGITATOR
FEED PUMP
AIR
BLOWER
SCRUBBING
TOWER
SCRUBBER WATER
TO
STRIPPING TOWER
CALCINE
COOLER
CALCINE

NEWS

(Continued from page 46)

HEAT TRANSFER SYMPOSIUM

A symposium on Heat Transfer will be offered during the Summer Session, at the University of Michigan, Ann Arbor, June 23 to Aug. 15. The symposium will be designed to meet the needs of advanced students, research engineers, and teachers in technical schools and colleges.

Lectures by visiting speakers will be given on Fridays and Saturdays, and those by members of the University of Michigan faculty on Wednesdays. All Wednesday and Friday lectures will be from 3 p.m. to 4:30 p.m., followed by a discussion period. The Saturday lectures will be from 10 a.m. to 11:30 a.m., also followed by a discussion period. The lectures will be given in Room 311, West Engineering Building.

For information concerning the requirements for graduate credit or the summer courses, correspondence should be addressed to Prof. Harold M. Dorr, director of the Summer Session, University of Michigan, Ann Arbor. For additional information about the Symposium on Heat Transfer, address Prof. W. W. Hagerty, department of engineering mechanics, College of Engineering, University of Michigan.

NATIONAL LEAD BUYS NICKEL PROCESSING

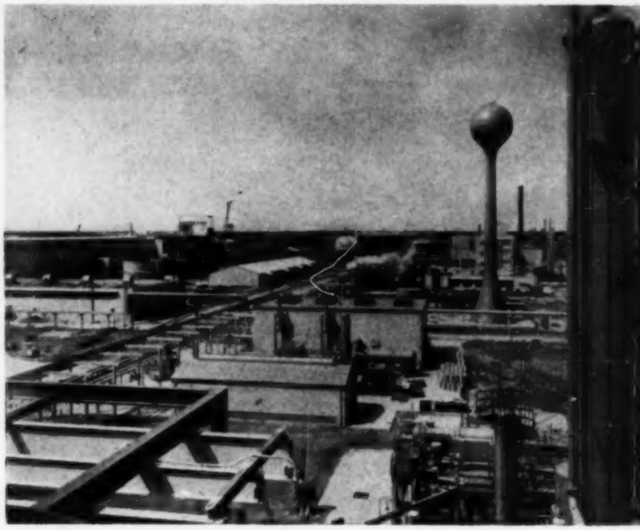
The National Lead Co. has acquired a majority interest in Nickel Processing Corp., operator of the Government-owned nickel plant at Nicaro, Cuba, according to Joseph A. Martino, president of National Lead. Mr. Martino indicated that National Lead Co. and Fomento Minerales de Cuba have purchased N. V. Billiton Maatschappij's interest in Nickel Processing Corp. and rights to certain processes which may further expand the output of the plant.

In February of this year, Jess Larson, Administrator of General Services, announced the resumption of nickel production at Nicaro. The unit was closed down after World War II and has been reactivated to provide vital nickel for the nation's defense industry. Full production at a rate of about 30 million pounds of nickel per year will begin in June.

Nickel Processing Corp. is presently conducting tests on a pilot plant basis which hold promise of increasing the capacity of the present facilities and also permitting the recovery of cobalt from the ores treated at Nicaro. National Lead Co. has under construction at the present time a plant unit at Fredericktown, Mo., which will also produce cobalt.

(More News on page 50)

NEW TETRAETHYL LEAD PLANT FOR ETHYL CORP.



The newest of industrial developments in Greater Houston, the Ethyl Corp. plant along the Houston Ship Channel, is about to begin production. It will manufacture Ethyl antiknock compound used in making antiknock gasolines.

A new plant for the manufacture of antiknock compounds will shortly be in full production at Houston, Tex. officials of the Ethyl Corp. announced last month.

Ethyl's new plant, which represents an increase of approximately one-third in Ethyl's tetraethyl lead capacity, "incorporates many technological improvements, process changes, and new engineering designs developed as a result of Ethyl's long experience in the field of antiknock compounds, according to E. L. Shea, president of the company.

Along with its Baton Rouge manufacturing plant, the company now has two separate plants each completely integrated as well as independent of the other.

The new Ethyl plant is situated along the south bank of the Houston Ship Channel about 17 miles from downtown Houston, on a tract of approximately 400 acres. The present buildings cover about 80 acres.

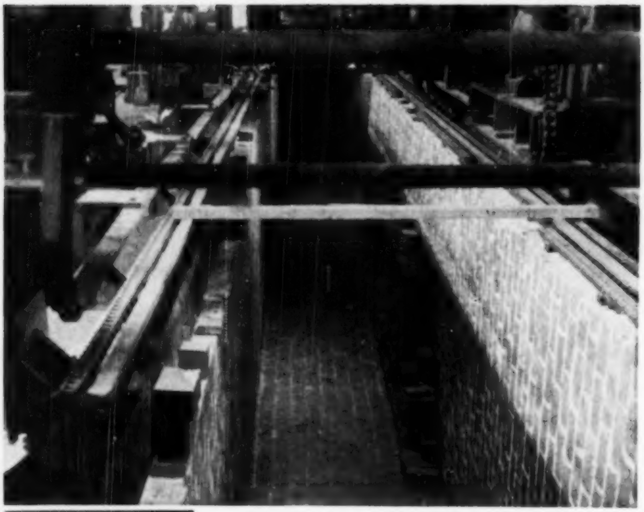
Ethyl's new Houston plant will provide its own requirements of the chemical intermediates needed in tetraethyl lead manufacture. These include sodium, chlorine, hydrogen chloride, ethyl chloride, ethylene dichloride, and lead-sodium alloy. The plant is divided into three operating areas—the sodium area, the ethyl chloride area, and the tetraethyl lead area. The plant also has an administration building, a centralized shops and stores area, a utilities area, and other auxiliary features.

The largest structure in the plant is the T-shaped sodium building, where sodium and chlorine are produced by electrolysis of salt. Already the world's largest producer of sodium, Ethyl is obtaining an increase in capacity with its new Houston installation.

In the ethyl chloride area, the first unit in the process is the hydrogen chloride plant, where hydrogen is burned with chlorine obtained from the sodium operations. The hydrogen chloride is then compressed and sent to the ethyl chloride unit, where it is reacted with ethylene to form ethyl chloride. Another unit in this area is the ethylene dichloride plant, where ethylene is added to chlorine to form ethylene dichloride.

In the tetraethyl lead area, the principal structure is the tetraethyl lead plant, where both the alloying and the tetraethyl lead operations are carried on. As a first step, metallic lead is reduced to its molten state. This molten lead is then combined with molten sodium to form the alloy which is used with ethyl chloride in the tetraethyl lead reaction.

The tetraethyl lead section of the building is four stories high. The manufacturing operation begins on the fourth floor, where the lead-sodium alloy and the ethyl chloride are introduced. After the basic reaction has been completed, the tetraethyl lead is washed and purified and then blended with other ingredients to form the finished antiknock compound.



CO-OPERATION BIG SHOT

(Continued from page 27)

of time between shot and the blast arrival in St. George, we know that the shocks the residents there heard were always those which traveled through the ozonosphere. On several of the shots Las Vegas, Caliente, Boulder City, Henderson, and Goldfield also received small shocks through the ozonosphere. Just like normal troposphere shocks, ozonosphere shocks are reflected when they strike the earth. In this manner, residents of Prescott (Ariz.), Milford (Utah), and Corcoran (Calif.) each heard one of the atomic bomb blasts."

Instrumentation

While most of the instruments used by the A.E.C. in measuring physical phenomena were not shown, correspondents were given a glimpse of the Control Point at Yucca Flats and of a typical bunker in the bomb area, housing recording instruments. For both air-drop and tower shots, bunkers are the heart of the data-recording service. They are versatile, and may be used to record different data for different tests. They are built of concrete, below ground level and are covered with a thick mound of earth, stabilized with an asphalt coating. Cost is anywhere from $100,000 to $600,000. Bunkers must be built to withstand the tremendous effects of detonations. Walls are about 3 ft. thick and doors are lead-filled to minimize radiation in the instrument room. Entrances are labyrinths, and each bunker is equipped with an air-cooling plant to remove the heat generated by the many instruments and motors operating during a test.

The detecting instruments for the most part are contained in the test towers (300 ft. high) and are contained in a cob at the top. Coaxial cables are used to transmit signals to the recording instruments in the bunker. For the most part, signals are photographed from high-speed oscilloscopes and the actual activation of the instruments and recorders is from the Control Point poised between Yucca and Frenchman Flats.

The official description of the Control Point as given out to correspondents, is as follows: "At the control point is a Class A weather central which receives weather information from all over the world through air weather service networks, as well as up-to-the-minute information on local conditions through stations manned specifically for these operations.

"Forecasts provided by this weather central make it possible to schedule tests in advance and to postpone if necessary in order to utilize optimum weather conditions. By means of the forecasts the height of the radioactive cloud, its track over the country and fall-out from it is predicted in advance.

"In a given test there may be as many as fifty aircraft empoyed for various purposes. Their functions vary all the way

(Continued on page 54)

CO-OPERATION BIG SHOT

(*Continued from page 52*)

from dropping a 'bomb' to providing essential transportation, and from making important experiments to assisting in radiological-safety surveys. They range in type from big B-45 jet bombers to tiny L-20 liaison planes. There are C-54s, jet fighters, and helicopters. The control of so many planes with so many jobs over a few square miles of land requires the utmost reliability of communications. Men and equipment for this purpose are available at the Control Point.

"Beyond this control of the operation there is also the control of the many experiments themselves. There are filaments to be turned on; power must be applied to many circuits; camera shutters must be opened and closed at exact moments; ultrafast as well as normal movie cameras must be started; blast-proof doors must be secured; some lights must be turned on, others turned off; in static tests the nuclear device itself must be armed and fired. These and hundreds of similar details must be taken care of without fail in proper order and at predetermined times in order that the desired information be obtained. This control is provided with a 'sequence timer' located in the control room. The device sends out electric signals which activate relays to perform the above tasks; it starts clocks to measure the times at which these signals are transmitted; it measures the time of the detonation; and it even starts itself—in the case of an air drop—when the bomb leaves the dropping aircraft."

As far as instrumentation is concerned, Dr. Gaelen L. Felt gave a limited insight as to how some of the problems of recording have been solved.

"Frequently," he said, "the most useful measurements are those of what takes place within the detonation itself. Since the measurements must be made in millionths of seconds—or less—the resolving of equipment must be incredibly short. To catch the immediate early phenomena of the detonation, the detectors and gauges must be placed on the tower in very close proximity to the unit being tested. This, of course, means that the detectors are almost instantly vaporized, but in the millionth of a second before they are destroyed, they transmit the all-important signal to the recording devices in the bunker.

"The electronic recording circuits respond extremely rapidly. They can be made to operate in a few hundred-millionths (0.00000001) seconds. A great deal of light is required to write on photographic film in such a limited time. Unless special precautions are taken, this light would badly fog the film during the many minutes the instrument is waiting for its signal to be given. To solve this dilemma the electron beam is reduced in intensity and deflected off the screen prior to zero time. At the last possible instant it is necessary to raise this intensity to its required value. The coaxial cable is tapped so that the signal itself can trigger an intensifier. The signal, however, passes through a greater length of cable and hence appears at the scope a microsecond or so later to be recorded after the intensity has been increased.

"The record is of very short duration. Fortunately, however, the fluorescent oscilloscope screen retains the image briefly

(*Continued on page 58*)

MARGINAL NOTES

(Continued from page 30)

Illustrations and tables are used liberally to supplement the written text, and probably account for 60 pages in the book. An appendix lists the properties of certain solutions, and numerical conversion factors.

The effectiveness of this book could be improved in certain respects. Graphs and diagrams are not always explained adequately. Numerical data of the figures will be of limited use, because usually they are not generalized beyond a single resin, and several of the operating variables are left unspecified. The entire development of the subject is factual with a minimum of explanation, so that the reader is left largely to make his own correlations and interpretations. However, these deficiencies reflect the complexity of the subject.

By providing a good introduction to the operations of water softening and deionization, along with a brief review of the rest of ion exchange technology, the book will serve to satisfy a widespread need.

A German Know-How

Der Steinkohlenteer und Seine Aufarbeitung. H. J. V. Winkler. Verlag Glueckauf, G. M. B. H. Essen. Germany (1951). 383 pp. $20.95.

Reviewed by Max Leva, Consulting Chemical Engineer, Pittsburgh, Pa.

THIS book presents a detailed discussion of the technology of high temperature coal tar, according to German practice. It consists essentially of two major parts of which the first describes the various processes that are in use for the preparation and refining of the numerous chemicals derived from coal tar. A detailed survey is given of many well-done flow diagrams on the type of vessels and units required for the individual operations. This part of the book, however, does not present detailed engineering data. The author takes up first batch and then continuous distillation of crude tar and proceeds then to a consideration of the processing of the various fractions, light oil, middle oil, etc., . . . to pitch. In connection with the latter, reference is made to its use for preparation of plastic masses. Dispersed through the first part of the book the reader finds summaries of the chemicals derived from various tar fractions together with considerable physical data pertaining to tar chemicals.

The second part of the book consists essentially of two main sections. The first contains detailed descriptions of the more important units met in tar processing. In some detail construction and

dimensions pertaining to piping, retorts, still pots, distillation columns, mixing vessels and auxiliaries are presented. In the remaining sections of the book specifications pertaining to a number of tar chemicals are listed and analytical testing methods are outlined. The book is excellently cross-indexed and should be of great value as a reference manual.

Tool Steel Handbook. Allegheny Ludlum Steel Corp., Pittsburgh 22, Pa. (1951). ii-ix + 197 pp.

Charts and tables give specific and comparative data on properties, analyses, and applications of this company's tool steels. Details descriptions of the important grades, and describes the many forms and finishes available from Allegheny Ludlum. Heat treating and handling techniques and a set of weight tables and other useful reference material included. Free copies of the volume will be sent to qualified persons on request to Allegheny Ludlum Steel Corp., 2020 Oliver Building, Pittsburgh 22, Pa.

A New and Bigger Merck

The Merck Index—Sixth Edition. Publication Department, Merck & Co., Rahway, N. J. (1952) 1167 pp. $7.00 for the regular edition; $8.00 for the thumb-index edition.

THE sixth edition of the Merck Index follows, by ten years, the prior volume. According to the publisher, 50,000 copies of the first printing of this new edition are already sold, and this fact alone places it well into the best-seller list as far as handbooks are concerned. It contains, in its 1167 pages of text, more than 8000 descriptions of individual substances, more than 2000 structural formulas, and more than 20,000 names of chemicals and drugs.

New features include a table of standard buffers for calibrating pH measurements; a table of radioactive isotopes giving half-lives and type of radiation, and a table of current medical uses for radioactive elements and compounds.

Another new section lists more than 300 organic "name" reactions with original and review references, with a description and structural representation of each reaction.

As the subtitle indicates, this is really an encyclopedia for the chemist, pharmacist, physician, and those in allied professions.

To list completely the Table of Contents, would be impossible, but more than a thousand pages are given over to chemicals and drugs, descriptions, physical properties, etc. In addition, there are many other sections of interest to technical men.

CO-OPERATION BIG SHOT

(*Continued from page 54*)

after the electron beam has swept across. The persistence of the image, analogous to a modern television tube where no flicker is discernible to the eye, is sufficient to permit permanent recording on the photofilm.

"These films are the raw data from which the results of the experiments are interpreted.

"After the shot, re-entry to the building and recovery of the data are made as soon as radiological safety precautions permit. This is normally within a few hours after the blast."

This is as much as we were able to learn of the tremendous scientific efforts behind an A.E.C. "experiment." The military problem was quite aside from our story, as is the impressive achievement of the creation of the proving ground itself. But we felt that behind the closed doors of secrecy, an enormous detailed task was being done, efficiently, by competent, brainy men, and that this test and those to follow, as well as those before, were advancing our country quickly and securely to firm understanding of nuclear forces.

The Blast

As for the blast itself, there is little to add to what has already been said. We chose to face away from detonation, and saw the desert grow white from the intense light of the nuclear release—some 35-40 times as bright as the sun, according to my calculations, where we stood. At the same instant, an intense heat wave was felt, of such power that one is thankful it lasted only a microsecond. After the first glare, the light dimmed, and we turned to a fireball, turbulent and churning, red and black. This snuffed out quickly, and in its place was a colored cloud, doughnut-shaped, twisting and rising. The desert lifted in a huge dust cloud, and the expected mushroom formed, but not for long. The stem quickly broke and the cloud now solid, rose, still pink, white, and salmon, to a tremendous height—40,000 ft., we learned later.

Somewhere during this time, the blast wave hit, loud and forceful, knocking my hat from my head. It came as a complete surprise, for though I knew of it, and had planned to time it, the events were such that when it came, it was unexpected. I suspect further that my mouth was still open in amazement and unbelief. After all, the instantaneous release of 2×10^{13} calories, just 10 miles away, is more than impressive; it is close to terrifying.

Half of Operation Big Shot was over. Now began the final phase of tracking, calculating, analyzing and deciding what science had learned, all pointing to the next experiment.

NEWS

ZEISBERG WINNERS, 1952

This year's winners of the F. C. Zeisberg Memorial Award for excellence in engineering report writing were announced at the April 8 meeting of the Philadelphia-Wilmington Section of A.I.Ch.E. at the Du Pont Country Club in Wilmington, Del. This award is offered in memory of the late Fred C. Zeisberg, National President of A.I. Ch.E., 1938.

G. S. Cochrane

Gordon S. Cochrane, a senior chemical engineering student at Drexel Institute was named first-place winner. Alfred F. Talbot, a senior at Villanova College, won the second prize, and the third prize went to Byron D. Babcock, a senior at the University of Delaware.

A. F. Talbot

The Zeisberg award is presented annually to the students submitting the best-written reports in connection with their regular academic studies and chemical engineering laboratory experiments. The competition is open to students selected by the following schools: Bucknell University, Drexel Institute of Technology, Lehigh University, Lafayette College, Princeton University, University of Delaware, University of Pennsylvania, & Villanova.

B. D. Babcock

Gordon S. Cochrane, a native of Philadelphia, at Drexel is a member of the Tau Beta Pi honorary engineering fraternity, Phi Kappa Phi, and the A.I.Ch.E. Student Chapter. He expects to join the staff of Sun Oil Co. at Marcus Hook.

Alfred F. Talbot was born and raised in Springfield, Delaware County. At Villanova he is a member of the student chapters of A.I.Ch.E. and A.C.S.

Byron D. Babcock, of Wilmington, won the Silco scholarship at the University of Delaware, where he is president of Delaware Alpha Chapter of Tau Beta Pi honorary engineering fraternity.

LOCAL SECTION NEWS

ENLISTED SPECIALISTS HOLD FIRST MEETING

On April 9, Army Chemical Center, Md., saw the first formal meeting of a new organization, "The Enlisted Specialists Chemical Engineering Club."

The guest speakers were Brig. Gen. W. M. Creasy, Commanding General of the Chemical Corps Research and Engineering Command, and Thomas H. Chilton, technical director of the engineering department of the Du Pont Co. and the 1951 President of the A.I.Ch.E.

General Creasy told the 200 young chemical engineers in the audience about the utilization of technical personnel in past emergencies.

Dr. Chilton's address was on "Why an Engineering Society?" He reviewed for his audience of young engineers the history of the modern engineering fields and their respective professional societies.

The formation of this club, referred to in "C.E.P." April, page 44, has been an outgrowth of a situation that has grown up at the Chemical Center in the past 18 months. During the Korean emergency, the Army has called up a great number of men with degrees in engineering or one of the sciences. At this time, there are about 900 men in this category who have been assigned to the Center under the Army's program of utilization of scientific and professional personnel. Of these 900, about 250 hold one or more degrees in chemical engineering.

The executive committee of the club are shown in the accompanying picture.

ST. LOUIS

The April 17 meeting was held jointly with the National Association of Corrosion Engineers with 65 members and guests in attendance at the pre-meeting dinner at the Forest Park Hotel. Later the group assembled at the nearby Engineers' Club to hear S. W. McCann on "Glass Lined Chemical Equipment." Attendance here was 151, including members from the Engineers' Club.

Mr. McCann first outlined the history of enameled and glass-lined vessels, then described the present-day methods for manufacturing the glass-lined equipment used by the chemical industry. He mentioned the new alkali-resistant glass, which has three to four times more alkali resistance than the standard glass lining.

Reported by D. S. Weddell

EAST TENNESSEE

The 32nd General Meeting was held March 3, at Building 89, Tennessee Eastman Corp., Kingsport, Tenn., at which 35 members and visitors were present.

Nathan W. Dougherty, dean of engineering, University of Tennessee, spoke on "Licensing of Engineers in Tennessee." Mr. Dougherty said all states now have licensing laws.

At the close of the meeting, many questions were answered by Dean Dougherty, who wrote "Engineering Registration."

Mr. McCann is factory manager of the Pfaudler Co., Rochester, N. Y.

Reported by Benjamin Thompson

SPECIALISTS OF ARMY CHEMICAL ENGINEERING CLUB

Reading clockwise: Sitting: Paul Mourier-Petersen, M.I.T., 1950; P. J. Ripepi, Pittsburgh, 1949; Co-Chairman: K. Vander Voort, Purdue, 1950; William Heneghan, Columbia, 1950; Co-Chairman: Cpl. John Ward, Delaware, 1950; Paul Oreffice, Purdue, 1949; Joseph Durra, Rose Polytechnic, 1945; Eugene O,Connor, California, 1949; James Fisher, Georgia Tech., 1950; Standing: Larry Bartlett, Iowa State, 1948.

TWIN CITY

The last meeting of the Twin City Section was held March 19, at the Augus Hotel in St. Paul. There were 40 for the dinner and meeting.

An introductory talk on "Guided Missiles" was given by Ted Swenson of Raymond Laboratories. Much of his information and background has come from his experience in World War II.

The major talk was by O. W. Greene of the Pfaudler Co. He discussed briefly the history and development of the Company and then demonstrated glass-lined mixers and agitators.

Reported by R. H. Fredrickson

NATIONAL CAPITAL

The April 9 meeting was held in the National Press Club Building. A pre-dinner feature of the meeting was a plant trip through the Christian Heurich Brewing Co. R. E. Gibson, director, applied physics laboratory, gave a talk titled "Research, Development, and Guided Missiles." During World War II he was director of Allegany Ballistics Laboratory.

Reported by D. P. Herron

CHARLESTON

The fifth meeting of the year was held at the Charleston Recreation Center March 18 with 119 members and guests present.

M. L. Murdock, manager of sales and engineering of the pump section, Norwood Works, Allis-Chalmers Manufacturing Co., discussed the design of centrifugal pumps from the standpoint of the manufacturer. He then took up the selection of centrifugal pumps for specific applications, and the key points of installation and maintenance.

R. G. Edmonds of the Kanawha Valley Technical Council Committee reported that the local activities for the observance of Engineers' Week were successfully carried out.

Reported by G. K. S. Connolly

OHIO VALLEY

This Section held a joint dinner meeting with the American Society for Quality Control at the Engineering Society Headquarters in Cincinnati, Ohio, April 16. The local section of A.S.Q.C. was host.

After the dinner A. V. Feigenbaum, manager of programming of General Electric's aircraft nuclear propulsion project, discussed "Managing Process Control." Dr. Feigenbaum covered the many factors to be considered in setting up a completely adequate system for process control.

Reported by N. W. Morley

(*More Local Section on page 63*)

THE MEMBERSHIP DRIVE IN THE PHILADELPHIA-WILMINGTON SECTION

JOHN LEE OLSEN

Sun Oil Company, Marcus Hook, Pennsylvania

THE Membership Committee of the Philadelphia-Wilmington Section of A.I.Ch.E. was organized in February, 1950, as a part of the over-all program set up by Council for the purpose of obtaining a higher percentage of eligible chemical engineers interested in the activities of the Institute. Since that time 130 applications, representing about ten per cent of the total section membership, have been processed by the committee. The purpose of this article is to outline for other local membership committees the methods used in organizing this drive and to acquaint all members with ways and means to help.

The first phase of the committee's job was to secure a list of major organizations in the area, together with the number of A.I.Ch.E. members in these organizations. The committee was fortunate in that member listings had just been compiled by the local section in connection with the problem of dues collection. It was assumed that the eligible nonmember engineers were distributed in the same proportion as the membership, and a rough conversion of four chemical engineers for every A.I.Ch.E. member was used.

Personal Contact Established

The primary object in setting up the Membership Committee organization was to insure that all nonmember chemical engineers would be contacted personally by a committee representative. For this reason it was felt that the maximum number of engineers that one person should be expected to represent was about 20-30. As a logical sequence, three different company classifications were set up:

Company Classification	Number of Chemical Engineers
Small	Less than 20–30
Medium	20–100
Large	Greater than 100

Work of Committee Representatives

In the smaller companies the appointed representative handled all work personally. In the medium-size companies the representative usually set up his own committee, and this could be done often according to departments or sections in the organization. In the large companies, committee representatives were obtained for the various major departments in the company. These representatives in turn would often set up their own committees so that the personal contact would be assured.

EDITOR'S NOTE

For the second year in a row, the Philadelphia-Wilmington Section has won the unofficial contest for obtaining the most members for the Institute. The chairman of the local group during both these drives was John Lee Olsen of the Sun Oil Co., and we decided to ask Mr. Olsen to prepare an article explaining the know-how, which was so successful. This is the fifth in the series on Institute activities. Others can be found in the March, 1951, issue on page 46; in the September, 1951, issue on page 48; in the December, 1951, issue on page 52, and in the March, 1952 issue on page 60.

The procedure generally followed by the local representative was to obtain the names of the chemical engineers in his company or department for whom he was responsible. In a properly organized drive, this number was small enough so that all the engineers were known personally by the representative. The list was then divided into members and nonmembers. The representative then contacted the nonmembers and tried to acquaint him with the advantages of Institute membership. It was stressed that the man should not be high-pressured into joining, but rather convinced that it was to his own benefit to join. In many cases he was invited to attend one of the local section meetings.

The applications obtained through the drive were sent to the chairman of the Committee for final checking and then forwarded to the National office. All applications distributed were stamped "Philadelphia-Wilmington Section" so that credit would be given the committee for any applications sent directly to the Institute office. Any success the committee has had during the past two years has been due to the working members of the committee. The organization developed here has worked out well, but without conscientious local representatives, the drive would have been a failure.

Important Role of Each Section Member

The original survey of the organizations in the area showed that between 15 and 30 per cent of the chemical engineers worked in small companies (those employing up to about five chemical engineers). This is a particularly difficult problem since it is impossible to have a representative in each of these companies. The local section has tried to help by including in the announcement of one of the meetings a short write-up requesting solicitation of prospective members by all members of the section. In addition, the drive has often been publicized at these meetings and the members advised about whom they should contact for membership information. It appears that no organized approach can be developed for this problem and the committee is dependent on the individual members in helping to convince these engineers that they would benefit by joining the Institute.

Success of Drive—Service to Institute

The 130 applications obtained to date represent only a small percentage of the eligible nonmember chemical engineers in the area. Working on this drive has shown us that many of these men are anxious to join the Institute but have failed to do so because of lack of knowledge or just plain inertia. In getting these men to apply, our Committee feels that we are doing a service both to them and to the Institute.

LOCAL SECTION NEWS

(*Continued from page 61*)

CENTRAL VIRGINIA

This Section held a dinner meeting at the Gables Hotel, Elkton, Va., March 21, 1952. Fifty-eight members and guests attended.

The appointment of L. E. Poese to serve as secretary-treasurer was announced.

C. E. Ford, assistant manager, industrial carbon department, National Carbon Co., gave a talk on the operations and problems of the Local Sections Committee of which he is chairman.

Mr. Ford then talked on "Recent Developments in Karbate Process Equipment." With the aid of projected slides he showed and explained how certain Karbate equipment designs were developed.

Reported by L. E. Poese

BATON ROUGE

A meeting was held March 6, 1952, in the Camellia Room of the Heidelberg Hotel. The guest speaker, H. Dayton Wilde, manager of research and development for the Humble Oil & Refining Co., talked on "Exploring and Drilling for Oil in the Gulf of Mexico."

The talk reviewed the history of oil activities in the Gulf up to date.

Reported by Richard H. Bretz

PITTSBURGH

At the April 2 dinner meeting, held at the College Club of Pittsburgh, Carl F. Prutton reviewed the critical availability of sulfur and the activities now going on in search of additional supplies of this key material in the national defense program. Dr. Prutton, who is vice-president and director of operations, Mathieson Chemical Corp., centered his remarks on the process for the recovery of elemental sulfur from the waste hydrogen sulfide content in sour petroleum gases.

Reported by Hugh L. Kellner

SOUTHERN CALIFORNIA

The April 15 meeting, held at Carl's Restaurant in Los Angeles, found some 100 members congregating to hear Forrest E. Haver, Jr., of the Dean Witter and Co., research department, discuss the dynamic character of the chemical industry and some of the reasons why managers of large financial institutions, insurance companies, and banks have always held chemical industry securities in the highest regard.

Mr. Haver pointed out that one of the basic reasons investors are interested in the chemical industry is its phenomenal growth.

Reported by Gale S. Peterson

FUTURE MEETINGS AND SYMPOSIA OF A.I.Ch.E.

Chairman of the A.I.Ch.E. Program Committee
Walter E. Lobo, The M. W. Kellogg Co., 225 Broadway, New York 7, N. Y.

MEETINGS

Chicago, Ill., Palmer House, Sept 11-13, 1952.
Technical Program Chairman: D. A. Dahlstrom, Chem. Eng. Dept., Northwestern University, Evanston, Ill.

Annual — Cleveland, Ohio, Hotel Cleveland and Carter Hotel, Dec. 7-10, 1952.
Technical Program Chairman: R. L. Savage, Dept. of Chem. Eng., Case Inst. of Tech., Cleveland 6, Ohio.

Biloxi, Miss., Buena Vista Hotel, Mar. 8-11, 1953.
Technical Program Chairman: Norman A. Spector, Vitro Corp., 233 Broadway, New York 7, N. Y.

Toronto, Canada, Royal-York Hotel, April 26-29, 1953.
Technical Program Chairman: Brymer Williams, Dept. of Chem. and Met. Eng., University of Michigan, Ann Arbor, Mich.

San Francisco, Calif., Fairmont and Mark Hopkins Hotels, Sept. 13-16, 1953.
Technical Program Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Annual—St. Louis, Mo., Hotel Jefferson, Dec. 13-16, 1953.
Technical Program Chairman: R. M. Lawrence, Monsanto Chem. Co., St. Louis 4, Mo.

SYMPOSIA

Distribution of Chemicals
Chairman: D. A. Dahlstrom, Northwestern University, Evanston, Ill.
Meeting—Chicago, Ill.

Monobed Ion Exchange
Chairman: F. J. Van Antwerpen, Editor, Chemical Engineering Progress, 120 East 41st St., New York 17, N. Y.
Meeting—Chicago, Ill.

Applied Thermodynamics
Chairman: W. C. Edmister, California Research Corp., Richmond, Calif.
Meeting—Cleveland, Ohio

Human Relations
Chairman: R. L. Demmerle, General Aniline & Film Corp., 230 Park Ave., New York, N. Y.
Meeting—Cleveland, Ohio.

Modern Statistical Methods in Chemical Engineering
Chairman: C. Daniel, Engineering Statistician, 116 Pinehurst Ave., New York 33, N. Y.
Meeting—Cleveland, Ohio.

Filtration
Chairman: F. M. Tiller, Dir., Div. of Eng., Lamar State College of Technology, Beaumont, Tex.
Meeting—Cleveland, Ohio

High Pressure
Chairman: E. W. Comings, Head, School of Chem. & Met. Eng., Purdue University, Lafayette, Ind.
Meeting—Cleveland, Ohio.

Mining, Metallurgical Techniques for Chemical Engineers
Chairman: To be announced later.
Meeting—Biloxi, Miss.

Chemical Engineering in Hydrometallurgy
Chairman: John D. Sullivan, Battelle Memorial Institute, Columbus, Ohio.
Co-Chairman: John Clegg, Battelle Memorial Institute, Columbus, Ohio.

Fluid Mechanics
Chairman: R. W. Moulton, Head, Dept. of Chem. Eng., University of Washington, Seattle, Wash.

Absorption
Chairman: R. L. Pigford, Div. of Chem. Eng., Univ. of Delaware, Newark, Del.

Authors wishing to present papers at a scheduled meeting of the A.I.Ch.E. should first query the Chairman of the A.I.Ch.E. Program Committee, Walter E. Lobo, with a carbon copy of the letter to the Technical Program Chairman of the meeting at which the author wishes to present the paper. Another carbon should go to the Editor, F. J. Van Antwerpen, 120 East 41st Street, New York 17, N. Y. If the paper is suitable for a symposium, a carbon of the letter should go to the Chairman of the Symposia, instead of the Chairman of the Technical Program, since symposia are not scheduled for any meeting until they are complete and approved by the national Program Committee. Before authors begin their manuscripts they should obtain from the meeting Chairman a copy of the Guide to Authors, and a copy of the Guide to Speakers. The first book covers the preparation of manuscripts, and the second covers the proper presentation of papers at A.I.Ch.E. meetings. Presentations of papers are judged at every meeting and an award is made to the speaker who delivers his paper in the best manner. Winners are announced in *Chemical Engineering Progress*, and a scroll is presented to the winning author at a meeting of his local section. Since five copies of the manuscript must be prepared, one should be sent to the Chairman of the symposium and one to the Technical Program Chairman of the meeting, or two to the Technical Program Chairman if no symposium is involved and the other three copies should be sent to the Editor's office. Manuscripts not received 70 days before a meeting cannot be considered.

LOCAL SECTION NEWS

(*Continued from page 63*)

NEW ORLEANS

A joint meeting of this Section with the Tulane University Student Chapter was held in the university's Mechanical Engineering Building, March 19, 1952.

Two papers, "Inauguration of the Chemical Engineering Practice School at Tulane" by Harry Osment, and "The Determination of Overall Heat Transfer Coefficients on Industrial Exchangers" by Thomas Farmer, were presented. Both speakers are senior chemical engineering students at the University.

The papers discussed, respectively, the objectives and plan of operation of the new practice school and its application to a specific problem. The practice school, probably the first of its type in the South, is operated in conjunction with the Pan-Am Southern Corp.

Reported by Edwin R. Cousins

STUDENT CHAPTER CONFERENCE IN VIRGINIA

Ten schools represented by 103 delegates attended the Third Annual Conference Mid-Atlantic Regional Group of Student Chapters of American Institute of Chemical Engineers held at the University of Virginia, Charlottesville, Va., March 28-29, 1952. The schools represented were: Johns Hopkins University, University of Maryland, West Virginia University, University of Delaware, Bucknell University, University of Pennsylvania, Pennsylvania State College, Drexel Institute of Technology, Villanova College, and University of Virginia.

The program included a party at the Engineers Club, a tour of the new chemical engineering laboratories, a social hour, presentation of eight student papers in Maury Hall, and a banquet. F. J. Van Antwerpen, editor, *Chemical Engineering Progress*, toastmaster at the banquet, presented the student paper awards. The principal speaker was Martin J. Bergen, engineering department, Du Pont Co., whose address was titled, "What Engineering Undergraduates Should Expect to Get Out of Technical Education."

Mr. Bergen's talk presented the problem as viewed by industry of combining needed liberal arts courses for engineers without sacrificing their technical instruction and this while keeping the time requirements as low as possible. The address evoked many questions and much discussion.

The students who received paper awards were the following: First prize to Robert G. Clark, Drexel Institute of

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LOCAL SECTION NEWS

(Continued from page 65)

Technology, for his paper, "Viscosity of Liquids"; second prize ($5.00), for "Solubility Behavior at Solvent Conditions Approaching the Critical" to Fu-Ho Chan, University of Pennsylvania, and the third prize to Clifford R. Woodford, University of Maryland, for his paper, "Industrial Waste Treatment." The first prize was $10.00, the second, $5.00, and the third prize an honorable mention award.

COLUMBIA VALLEY

On April 10 a Symposium on Heat Conduction was held by this Section. More than 60 members and guests were in attendance.

The four speakers and the symposium chairman were all members of General Electric Co., Hanford Works. The chairman was Dr. W. K. Woods, assistant manager, technical section. The speakers and their topics were:

J. R. Triplett—**Mathematical Approach to Heat Conduction.**
R. S. Vanderwater—**Use of Schmidt-Binder Graphical Methods for Heat Conduction Under Transient Condition.**
G. M. Roy—**Application of the Electrical Analogue to Heat Conduction Problems.**
M. Altman—**The Use of Emmon's Relaxation Method for Heat Conduction—Steady State.**

A joint meeting of this Section and the American Society of Metals was addressed March 26, 1952, by Truman S. Fuller. Mr. Fuller, who is national president for the American Society for Testing Materials and a representative of the General Electric Co., Schenectady Works Laboratory, spoke on "Progress in Materials for the Electrical Industries During the Past Fifty Years."

Reported by C. F. Falk

PHILADELPHIA-WILMINGTON

The sixth and last meeting of the 1951-52 season was held at the Du Pont Country Club, Wilmington, Del., on April 8, 1952. About 90 persons attended the dinner and 150 the meeting that followed.

Officers elected who will be in office for the one year period which began May 1, 1952, are as follows:

Chairman—Wm. E. Chalfant, Atlantic Refining Co.
Vice-Chairman—Roy Kinckiner, Du Pont Co.
Corres. Sec.—Wm. E. Osborn, Atlantic Refining Co.
Rec. Sec.—Theodore A. Burtis, Houdry Process Corp.
Treasurer—Wm. A. Bours, DuPont Co.
Asst. Treas.—Harry L. Bolton, Phila. Quartz Co.

Executive Comm.—Richard B. Chillas, Retired; Jack C. Dart, Houdry Process Corp.; T. W. Tomkowit, Jr., Du Pont Co.

The speaker of the evening was Erik Braun of Merck and Co., Rahway, N. J. who talked on "Engineering Aspects of Antibiotic Manufacture."

Reported by Wm. E. Osborn

NORTHERN CALIFORNIA

At the March 17 dinner meeting held at the Engineers' Club in San Francisco, the 121 persons attending heard a talk on "Chemical Engineering Applications of Radioisotopes" by Jerome Kohl of the Western Division of Tracerlab, Inc. To supplement his talk, Mr. Kohl exhibited some instruments used in connection with radioisotopes.

Reported by D. F. Rynning

WASHINGTON-OREGON

The first annual student tour and joint A.I.Ch.E. Junior Chapter dinner meeting was held April 23-25. The program of industrial tours was arranged as follows:

April 23:
- Nalleys, Inc., Tacoma, Wash.
- Parker Paint Co., Tacoma
- Fleischmann Yeast Co., Sumner, Wash.
- St. Regis Kraft Co., Tacoma
- Wypenn, Tacoma

April 24:
- Stauffer Chemical Co., Tacoma.
- Tacoma Smelter, Tacoma
- Du Pont Chemical Co.
- Hooker Electrochemical Co. } Choice
- Pennsylvania Salt Mfg. } Choice

April 25:
- Union Oil Refinery, Edmonds, Wash.
- Sick's Brewery, Seattle
- North Coast Soap Co., Seattle
- Bethlehem Steel Corp.
- Superior Portland Cement Co.
- Air Reduction Pacific Co.

Following dinner, which was held in the Windsor Room of the New Washington Hotel, April 25, there was a panel discussion on "Job Orientation" at which Roger Chase of the R. E. Chase Co., was moderator.

The following speakers discussed the place of the chemical engineer in their respective fields:

Management—T. E. Moffitt, gen. mgr., Hooker Electrochemical Co.
Teaching—George Austin, prof. Washington State College
Production—J. W. Hastings, supt., Edmonds asphalt plant, Unoin Oil Co.
Development—Clark Heritage, vice-president in charge of development, Weyerhaeuser Timber Co.
Patents—Wright Arnold, patent lawyer
Engineering—W. S. Munro, chief chem. engr., Monsanto Chemical Co.
Consultancy—Charles Smith, Northwest Laboratories
Sales—Fred Armbruster, sales mgr., Dow Chemical Co.

Reported by J. T. Stephan

LOCAL SECTION NEWS

(*Continued from page 67*)

ROCHESTER

The fifth meeting, held March 19, 1952, was a joint meeting with the Student Chapter of A.I.Ch.E. at the University of Rochester, held in Chemistry Building, University of Rochester.

The speaker of the evening was Malcolm H. Barnes, development engineer, Linde Air Products Co., Tonawanda, N. Y., who talked on "Synthetic High Temperature Crystals." He traced the development of the synthetic crystal industry both in Europe and the United States. He pointed out that most of the crystals including the synthetic sapphire and ruby were basically alumina crystals but that the titania crystal was coming into use in this country as a synthetic gem stone.

There were approximately 55 people at the dinner preceding the meeting. Of the number attending, approximately 20 were from the student chapter. There was a total attendance of approximately 85 at the meeting itself.

Reported by Irving Siller

MIDLAND

At a joint meeting with Midland Section of the A.C.S., on March 31, in Dow Auditorium, Llewellyn Heard, research chemist of Standard Oil Co. (Ind.), gave his presentation of "The Story of Fire." This lecture demonstration was well attended with more than 400 people. This talk designed for nontechnical audiences, illustrated surface, combustion, ignition temperature, oxygen availability, etc.

Ray L. Geddes, consultant for Stone & Webster Engineering Corp., addressed 115 members and guests on "The Efficiency and Capacity of Bubble Cap Trays" at the March 27 meeting at the Dow Auditorium. He told of the factors in the design of a bubble tray that have not been fully rationalized in the literature and where judgment and experience are still involved. He discussed the work of Gerster & Colburn et al on foam height on trays.

Reported by Raymond Duddleston

CHICAGO

About 200 members and guests met in Vogel's Restaurant in Whiting, Ind., March 24, to hear R. C. Gunness, assistant general manager of manufacturing, Standard Oil Co. (Ind.) speak on "Function and Purpose of the Government Committee on Scientific Advancement." Dr. Gunness related his experiences in Washington as vice-chairman of the Research and Development Board of the Department of Defense.

Reported by Thorpe Dresser

PEOPLE

S. R. Bell has been appointed principal engineer on synthetic resins and plastics of the chemical division of Blaw-Knox Co., Pittsburgh, Pa. Prior to his recent affiliation with Blaw-Knox, Mr. Bell was assistant chief engineer for a chemicals producer and earlier in his career had extensive experience in synthetic resins and related processes. He received his M.S. degree in 1941 from the University of Pittsburgh.

Jerome T. Coe has recently been appointed manager of sales development at the General Electric chemical division's silicone plant at Waterford, N. Y. He started his career with General Electric in the research laboratory at Schenectady and from 1943-46 he served in the U. S. Navy. On his return he was employed in the chemical engineering division of G. E. and in 1948 was put in charge of process engineering at the Waterford plant, a position he held until his recent appointment. He received his B. S. degree in chemical engineering from M.I.T.

Bion D. Barger, Jr., a former student at the University of Washington, Seattle, Wash., has assumed the position of research chemical engineer for the M. W. Kellogg Co., Jersey City, N. J.

Eugene P. Shoch, professor of chemical engineering and director of the Bureau of Industrial Chemistry at the University of Texas, was recently elected to life membership in the So. Texas Section, A.I.Ch.E. His career has included professional duties as a civil engineer, teacher, musician, research scientist, and editor.

At the University of Texas in 1916 he initiated a course in chemical engineering, was instrumental in enlarging the chemistry department to include chemical engineering, and in establishing, in 1940, a separate department of chemical engineering. Dr. Schoch received his B.S. degree in 1894 and his M.A. in chemistry two years later. His Ph.D. was awarded in 1902 at the University of Chicago.

A member of A.I.Ch.E. since 1925, he is the first member of this Section to receive the lifetime membership award.

(*More About People on page 70*)

PEOPLE

(*Continued from page 69*)

G. F. Kline F. C. Cunningham M. J. Gould

The Vulcan Copper & Supply Co., Cincinnati, Ohio, recently announced three appointments to key positions:

Merle L. Gould as chief development engineer; George F. Kline as project engineer, and F. Corson Cunningham as process engineer.

Mr. Gould is a graduate of the University of Nebraska, and for the past nine years, has been associated with the Shell Development Co., at Emeryville, Calif. Mr. Gould is heading up the development department of Vulcan engineering division. Mr. Kline has been associated with several companies in the chemical industry over the past ten years, including a period at the Atomic Energy Commission's installation at Oak Ridge, Tenn. He received his bachelor's degree in chemical engineering from Cooper Union College and his master's degree from New York University. Mr. Kline is a group leader on engineering products in the process engineering department. Mr. Cunningham has just completed work for a Ph.D. degree in chemical engineering from Yale University and is carrying out chemical plant design assignments as a member of the process engineering department. Mr. Cunningham was associated with the Chemical Construction Corp., New York, for several years. During World War II he served as a fighter pilot with the Air Force.

Robert Treat, Jr., of General Electric, has recently been made supervisor of customer service at the company's chemical division silicone plant at Waterford, N. Y. Previously he was a research assistant and later was assigned to pilot plant work on silicones. He was named a technical supervisor at the Waterford plant (1947), promoted to general foreman (1948) and named supervisor of product service (1950). Following graduation from M.I.T. he was employed by the Goodyear Tire & Rubber Co. as a technical superintendent.

Alfred S. King, formerly affiliated with the Houdry Process Corp., Philadelphia, Pa., is now in charge of technical sales-service for the Wilson Meyer Co., San Francisco, Calif.

Robert J. Wolf has recently been appointed manager of the sales development laboratory of B. F. Goodrich Chemical Co., Cleveland, Ohio. After receiving his Ph.D. in chemical engineering from Case Institute of Technology, Dr. Wolf taught at Princeton University prior to serving three and a half years with the Navy.

Louis T. Lanz, a research chemical engineer with Monsanto Chemical Co., has been named assistant to B. E. Thomas in the organic chemicals division's technical personnel procurement program. He received his B.S. degree in chemical engineering from the University of Wisconsin and immediately joined Monsanto. Before assuming his present duties in the St. Louis research laboratories he held several administrative positions at the company's William G. Krummrich plant in Monsanto, Ill., and at the company's central research department in Dayton, Ohio.

David B. Ardern has recently been put in charge of technical service at Houdry Process Corp. He joined the corporation in 1942 and has been engaged primarily in process design, concentrating on the commercial design of Houdriflow moving-bed catalytic cracking reforming of petroleum naphthas to aromatics and high octane gasolines. He received his B.S. and M.S. degrees in chemical engineering from the University of Louisville.

Richard H. Wilhelm, professor of chemical engineering at Princeton (N. J.) University, and **Walter Whitman,** on loan to the government from M.I.T. where he is head of the department of engineering, were among the civilians who witnessed the demonstration of the new chemical corps munitions and battlefield techniques shown at the Army Chemical Center, Md.

Henry L. Cox was recently elected vice-president in charge of the chemical division, at Argo, Ill., by the board of directors of Corn Products Refining Co. Before joining Corn Products in 1944, Dr. Cox had been associated with several large food and industrial concerns, and Mellon Institute. During World War II, on loan from the Carbide and Carbon Chemicals Co., he served with the Rubber Reserve Corp. at Washington, D. C.

A graduate of the University of North Carolina (B.S. chemical engineering) and the University of Chicago (Ph.D.), Dr. Cox is known for his interest in the making of synthetic gems.

(*More About People on page 74*)

CLASSIFIED SECTION

Advertisements in the Classified Section of Chemical Engineering Progress are payable in advance, and are placed at 15c a word, with a minimum of four lines accepted. Box number counts as two words. Advertisements average about six words a line. Members of the American Institute of Chemical Engineers in good standing are allowed one six-line insertion (about 36 words) free of charge per year. More than one insertion to members will be made at half rates. In using the Classified Section of Chemical Engineering Progress it is agreed by prospective employers and employees that all communications will be acknowledged, and the service is made available on that condition. Boxed advertisements are available at $15 per inch. Size of type may be specified by advertiser. In answering advertisements all box numbers should be addressed care of Chemical Engineering Progress, Classified Section, 120 East 41st Street, New York 17, N. Y. Telephone ORegon 9-1560. Advertisements for this section should be in the editorial offices the 15th of the month preceding the issue in which it is to appear.

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If you believe you're fully qualified, please write to us at 630 Fifth Avenue, New York 20, New York. We'll acknowledge your letter, and interview all qualified men. We'll respect your confidence. Please do not phone, or call in person. No such application will be considered.

SITUATIONS WANTED

A.I.Ch.E. Members

CHEMICAL ENGINEER — Experienced in handling design and erection for the complete plant as project engineer. Bulk of experience in detergents, pharmaceuticals, and organic chemicals. Seeking position as chief engineer. New York area. Box 1-5.

CHEMICAL PROCESS ENGINEER—B.Ch.E. Age 33. Eleven years' experience in process design and plant development work in petrochemical, butadiene, ammonia, and nitrogenous fertilizer plants where knowledge of distillation, thermodynamics, absorption, heat transfer, etc., were required. Exceptionally well qualified through previous positions for economic evaluation of and development engineering for new projects. Present salary $10,000. Desire engineering position with small or medium-sized organic chemical or petroleum refining operating company. Box 2-5.

EXECUTIVE CHEMICAL ENGINEER—B.Ch.E. Licensed, with over twenty years' substantial management experience in production and engineering of caustic/chlorine and organic operations. Seeking connection with broad responsibilities. Box 11-5.

CHEMICAL ENGINEER—B.Ch.E., June, 1950. Age 26, single. Eighteen months' design work experience. Desire work in production or development. Box 12-5.

CHEMICAL ENGINEER—Twelve years' experience research and development, chiefly organic chlorine compounds. Desire responsible job in development work. Northeast preferred, but not essential. Box 14-5.

CHEMICAL ENGINEER—Fourteen years' progressive experience process development, evaluation and design, technical sales and process equipment design. Industrial experience: petroleum refining, sugar and paper production, compressed and liquefied gas production and distribution. Advanced degrees. Publications. Age 38. Desire responsible position N. Y.-N. J. area. Box 13-5.

CHEMICAL ENGINEER—B.S., Tau Beta Pi, family. One year of process engineering experience in synthetic organic chemicals. Desire production engineering work with progressive company manufacturing chemicals in tonnage lots. Box 15-5.

PROCESS ENGINEER — M.Ch.E. 1947. 4½ years' experience in development, process design, project engineering. Engineer in Training—New York State. Age 27, single. Process or survey position desired. Box 16-5.

CHEMICAL ENGINEER — Diversified experience in process design, development, project engineering, process evaluation, management engineering, and production supervision. Desire challenging work with administrative potential. Box 17-5.

CHEMICAL ENGINEER—B.Ch.E. 1950. 24, single. Desire position in chemical engineering aspects of equipment design. Two years' experience mechanical design and drafting of pressure vessels and storage tanks. Box 18-5.

CHEMICAL ENGINEER—M.S., 34. Twelve years' diversified process engineering experience all phases petroleum refining, including technical service in operation of plant equipment, development of process studies and design. Prefer Northeastern location. Box 19-5.

CHEMICAL ENGINEER — B.S. 1948, M.S. 1951, University of Southern California. Age 26. Married. Diversified experience in production and pilot plant operation. Responsible. Production or design work desirable. Prefer West Coast or Southwestern location. Alien. Box 20-5.

CHEMICAL ENGINEER—Purdue 1949. 28, married. Three years' diversified experience in process and product development, production supervision, quality control, some technical service. Desire position with progressive company in technical sales or production. Box 21-5.

CHEMICAL ENGINEER, PROCESS OR DEVELOPMENT—M.S. Registered, ten years' experience college teaching, development and process control. Desire opportunity to utilize experience in responsible position leading to technical management. 35, family. Western location preferred, available June. Box 22-5.

CHEMICAL ENGINEER—Two and a half years' development and pilot plant experience. Married, age 26. Desire position preferably in the Southwest. Box 23-5.

CHEMICAL ENGINEER—B.Ch.E. 29, married, two children. Eight years' experience in development and production of synthetic resins and acrylic fibers. Seek responsible position in fibers field. Eastern location preferred. Box 24-5.

CHEMICAL ENGINEER — Seeking employment in Western Europe. B.S. 33, married, family. Eleven years' research and production experience, publications and patents. Strong plant operating background. Will accept long term contract. Full information supplied on request. Box 25-5.

RESEARCH ENGINEER—Chemist, chemical engineer, metallurgist, B.A. in Liberal Arts, M.S. in Chemistry, twenty years' diversified experience including twelve as chief chemist for large public utility. Seek position as Director of Research, Chief Engineer, etc. Box 26-5.

CHEMICAL ENGINEER—B.S. Ch.E. 1947. Age 31, single. Four years' experience in pilot plant work. Experienced in handling plant personnel. Desire work in operations or development. Prefer Midwest, Southwest, or West location. Box 27-5.

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CLASSIFIED SECTION

(*Continued from page 73*)

CHEMICAL ENGINEER—Nine years' process engineering experience with gasoline department of major independent oil company. Desire to affiliate with medium sized company as supervisor of operations or technical assistant to superintendent of gasoline or petrochemical plant, or refinery. Married, 30. Middle West or West Coast. Box 28-5.

PROCESS ENGINEER—B.Ch.E. except for thesis. Ten years research, development, design, pilot plant, production. Thorough knowledge of plastics, polymers, latex, organic chemicals. Permanent, responsible position desired with growing concern in design, production, or research. Box 29-5.

CHEMICAL ENGINEER—26, B.S. 1946. Four years design, operation, and development on coal synthesis gas pilot plants; laboratory and field scale. Two years plastics evaluation. Publications. Army Discharge early September. Prefer development or production. Box 30-5.

PEOPLE

(*Continued from page 71*)

SOMOGYI SUCCEEDS MATTHEWS AT MONSANTO

Erwin G. Somogyi, now serving as associate research director of Monsanto Chemical Co.'s plastics division, has been appointed director of research for the company's Merrimac division. He succeeds Frederic L. Matthews of Winchester, Mass., who resigned to become technical director of the research section of the Socony-Vacuum Co.'s research and development laboratory in Paulsboro, N. J.

Born in Budapest, Hungary, Somogyi came to the United States in 1923. He was graduated from Michigan University, where he received a B.S. degree in chemical engineering in 1935.

Somogyi joined Monsanto in 1935 and was assigned to the control laboratory of the company's organic chemicals division in St Louis.

Henry Wessel is now with the Midwest Research Institute, Kansas City, Mo. He was formerly with Monsanto Chemical Co. He received his B.S. degree in chemical engineering from Illinois Institute of Technology.

Walter Lapple, formerly with the Dorr Co., Westport, Conn., is now with Midwest Research Institute, Kansas City, Mo. He received his B.S. degree in chemical engineering from Cooper Union.

D. H. McCondichie, affiliated with Merck & Co., Inc., since 1951 as a chemical engineer, has been appointed plant engineer of the new Flint River plant, Elkton, Va. Previously he was senior standards engineer in the industrial engineering department, chief of the standards section in the same department, and then field project engineer in charge of the construction of the Flint River Plant. He received his B.S. degree in chemical engineering from the University of Alabama.

Louis F. Ray, of Chemstrand Corp.'s new nylon plant at Pensacola, Fla., has been appointed superintendent of Intermediates. Prior to his association with Chemstrand in 1951, he was affiliated with Monsanto Chemical Co. in supervisory capacities from 1939 to 1951. He received his B.S. degree from St. Louis University.

L. E. Dequine, Jr., has recently been appointed plant engineer of the Chemstrand Corp.'s nylon plant now under construction at Pensacola, Fla. Before joining Chemstrand in June, 1951, he was chief engineer for nine years at American Bemberg division of Beaunit Mills, Inc., Elizabethton, Tenn. He received his B.S. degree in chemical engineering from the University of Wisconsin in 1935.

W. E. Kennel has been appointed group leader in the process economics section of the process division at Standard Oil Co. (Ind.). He became associated with the company in 1948 as a chemical engineer. He did his undergraduate work at the University of Illinois and received a Ph.D. degree from M.I.T.

L. W. Russum of Standard Oil Co. (Ind.) has been made section leader heading the process economics section of the process division. He joined Standard in 1947 as a chemical engineer and became group leader in 1948. He is a graduate of the University of Arkansas and received his doctor's degree from M.I.T.

E. W. Kane, of Standard Oil Co. (Ind.), has recently been promoted to group leader in the process economics section of the process division. He joined the company in 1947 as a chemical engineer. He graduated from Case Institute and received his master's degree from M.I.T.

Necrology

F. C. BOWMAN

Frederic Charles Bowman, director of research, A. R. Maas Chemical Co., Los Angeles, Calif., since 1928, died recently. A graduate of the University of Toronto, Mr. Bowman first served the Canada Chemical Co., London (Ont.) Canada, as assistant chemist and subsequently was assistant chemist of the General Chemical Co., New York. After a period of three years as chemist with the Nichols Chemical Co., in Sulphide (Ont.), Can., he returned to the General Chemical Co. where he remained for some twelve years. For Maas he also gave part time to general consulting work on numerous short problems involving economics, patent law, sales policies, legal chemistry, etc.

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